A SIMULATION MODEL OF AN AIR CARGO IMPORT TERMINAL

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SUMMARY

This thesis presents a simulation study of the material flow system in a highly mechanized air cargo import terminal with limited space availability. Most existing research in this area has focused on specific activities in the terminal, such as automated storage and retrieval systems. Highly mechanized system in air cargo terminal does not guarantee an effective material flow system if without an effective working policy. Without studying realistically the impact of interaction effects among the activities, it is hard to produce an effective working policy. This research is the first attempt to use simulation to study the interaction effects among activities and storage systems in the terminal. We describe the main activities that need to be modeled in building a realistic and accurate simulation of an air cargo terminal. It is often difficult to characterize the attributes of the air cargo and we propose a systematic procedure to overcome this difficulty. Finally, we show how simulation can be used to evaluate existing and proposed working policies.

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CHAPTER 1: INTRODUCTION

1.1 Motivation

Since 1990, worldwide air cargo traffic has grown at an average annual rate of 6.3%. It is predicted that worldwide traffic will grow from 137.4 billion RTKs (Revenue tonne-kilometers) in 2001 to 475.5 billion RTKs in 2021. At the 20th International Air Cargo Association (TIACA) Air Cargo Forum, a list of top 10 cargo airports in the world showed that more than one-third of them are in Asia. Asia is characterized by a changing market environment that provides strong growth and opportunities in air cargo. There is the need for support from government, airports and terminals as well. To survive the changing environment, undoubtedly ground handlers also have to change.

Due to low production costs, Asia becomes the source for relatively low value items like shoes, toys and garments. Today, Asia's manufacturing sector is better equipped, more sophisticated and with high production skills. Asia is becoming a major sourcing origin for most multi-national companies. As the product lifecycle becomes shorter and shorter, more and more companies are going to outsource products and materials in order to reduce their risk and inventory and at the same time more and more production lines are going to be established in Asia. Hence, as the variety increases, so does cargo volume.

It can be seen that the competition among the air cargo terminals in Asia is intense. For instance, since 1990 Hong Kong, Manila, Shenzhen, Singapore and Taipei are locked in a battle to be a market leader for express cargo. The winner could reap a bounty worth

USD 100 million through lower prices and enhanced airport revenues and enjoy abundant new commercial opportunities as well. Hong Kong risks losing its bid to become the cargo hub because it has not yet taken the appropriate steps to enhance its viability. Again, this stresses the need for the improvement of air logistics operations especially air cargo ground handling operations, in order to win the air cargo business.

The limitation of space available in certain countries such as Singapore, Hong Kong, etc., is another challenge to ensure the survival of their air cargo terminals in the Asian region. Highly mechanized and high density storage systems are normally opted as the solution to tackle this space limitation issue. However, without a proper working policy, highly mechanized system alone is insufficient to maximize the benefit of the high technology. But this is still not the worst part. The worst part is that one can be stuck at a junction and has a hard time to select a right working policy when there is no evaluation tool to assist.

Therefore, in order to capture the increasing air cargo business under the stiff competition environment compounded with the space limitation problem, it is crucial for air cargo terminals to adopt a proper management strategy that addresses both operations efficiency and effectiveness, particularly at those terminals that have a significant market share of the air cargo trade. Shortly, air cargo terminals need to have effective working policies and a right evaluation tool in order to maximize their competitive strength. The intent of this thesis is to provide the solution to this.

1.2 Background

Air cargo terminals generally function as warehouses, involving physical activities such as receiving, break bulking, storage, retrieval and consolidating or palletizing of cargo. Due to the time-sensitive nature of the air cargo trade, the challenging part of terminal operations is to streamline these activities so that they can be completed within a short time period. Cargoes are meant to stay in the terminal only for a short period of time, during which they have to be processed either to be loaded to a carrier, or collected by consignees or freight forwarders/cargo agents. Timeliness in operations is therefore important as both carriers and freight forwarders have tight schedules. At most of the busy airports, operational problems are further compounded by temporal variations in workload, due to concentrations of flight arrivals or departures within narrow time windows.

We had the opportunity to study the operations of an air cargo hub terminal at a leading international airport that handles high cargo volume from many airlines, and experiences high variation in the workload across time. Like many other hub terminals situated at strategically located airports, the layout of this air cargo terminal is limited by space, as the leasing of space is very expensive. We observe that such air cargo terminals are designed with heavily mechanized and high density storage systems. For example, they may have automated storage and retrieval systems (AS/RS) for storing small or medium size cargo, pallet/container holding systems (PCHS) for storing large pallets, elevated transfer vehicle systems (ETVS) for retrieving and storing large pallets, and conveyor systems for transferring pallets, in addition to conventional racking systems for storing irregularly shaped cargo, and forklifts for moving cargo between storage systems and receiving/outbound areas. With a high density storage system and limited space, it is challenging for the terminal to devise ways to overcome or mitigate the consequential problems of longer storage and retrieval time, caused by congestion and extra handlings.

It is not uncommon for a busy air cargo terminal to handle cargo arriving in freighters or passenger planes throughout the day, from many different airlines. Cargo belonging to different shippers is consolidated and transported on aircraft in the form of Unit Load Devices (ULDs). Upon arrival, ULDs need to be broken loose (deconsolidated) to facilitate collection by cargo agents. These break-bulk operations are carried out at terminal workstations after the ULDs are transferred from the airside. Due to the weight and size of ULDs, a roller conveyor system is often used to transport them from the receiving dock to the workstations. Depending on the size or shape of cargo after break bulking, it will be directed to different storage locations. For example, an intact pallet, or a partial pallet holding a large amount of cargo belonging to a single agent, may be stored at a PCHS. Cargo of small or medium size may be stored at an AS/RS, and cargo of irregular shape or large size may be placed on a conventional racking system. A roller conveyor system is used to transport pallets to a PCHS from the workstations, while forklifts are used to transport other cargo to an AS/RS and conventional racking systems. It is a usual practice that outbound cargoes do not share the resources of inbound cargoes and vice versa, as resource sharing may lead to cargo mishandling which can be very costly to the ground handler's reputation and the airline's business.

We also observe that when cargo agents come to collect cargo, forklifts are used to retrieve the cargo from the three storage systems (i.e., AS/RS, PCHS & conventional racking system), and transport it to the truck docks. However, it is also possible that cargo can be transported to the cargo agents directly from the break-bulk workstations, especially if they arrive at the terminal while the cargo is still in the break-bulk process at the terminal workstations. To complete the handover, cargo sent by the forklift operators to the truck docks must be checked by the cargo agents to ensure that it is in the right quantity and in the proper condition. After the handover, the cargo agents are allowed to build up unconsolidated cargo into standard skids that can be loaded compactly into trucks. In response to all these, we propose several practical strategies to allow the terminal to utilize its resources more effectively, so as to minimize the turnaround time of air cargoes in the system.

To verify whether the proposed strategies are more effective or not a simulation method is proposed to model the cargo flow in the system and to study the impact of alternative strategies on the performance of the terminal. This approach is more appropriate and feasible than a purely analytical approach, because of the high degree of interaction between the material handling systems and the storage systems, and the fact that the material flow is partially determined by stochastic request times from the consignees or freight forwarders/cargo agents. To our knowledge there is no closed-form mathematical formula to represent the congestion effects due to the movement of the forklifts.

In addition, many different activities can happen within an air cargo terminal. From ULD receiving process up to cargo collection by cargo agents at the truck dock, it involves many ground handling jobs such as break bulking, cargo storing, retrieving and skid-building. Each activity requires a very different time range. Some cargoes might need to be stored at a conventional racking system instead of other storage system such as AS/RS. Or, the cargoes can be sent directly to the truck dock rather than being stored at the racking system. The number of scenarios is exponentially high. This compels us to select the simulation technique and not the mathematical approach.

We develop the simulation model using AutoMOD to study the cycle time of inbound (import) cargo. To capture the performance metric correctly the model simulates the complete range of activities in the cargo flow process, from the retrieval activities to the hand-over to the cargo agents. In addition, the activities involving the break bulking of incoming pallets from the airside are also included in the model, as they share common resources with the retrieval activities. After validating the model with the actual data, the model is then used to evaluate the impact of certain proposed strategies on cycle time.

Since forklifts are common resources used for retrieving as well as storing cargo, they play an important role in the terminal operations. Another critical resource (from the point of view of the terminal manager) is the limited number of truck docks. During the peak period, we observed that cargo agents often had to wait at the truck docks for forklift operators to bring out their cargo; sometimes they had to wait simply to secure a truck dock. It is not clear that adding more forklifts will alleviate this problem, because the induced traffic congestion may dampen or slow down the system considerably. On the other hand, the speed of activities at the truck docks also affects system operations, as forklift operators can start new jobs only after the cargo agents finish their skid-building and checking operations. Conceivably, the allocation and utilization of these resources affects the speed of system operations. Nonetheless, it is not certain what should be the right resource level and the best utilization policy, as these factors relate to each other dynamically. To study the interplay of these factors, we use our simulation model to examine the essential operations of the terminal such as the optimal number of forklifts, the effectiveness of our proposed truck dock allocation policy and the impact of the skid-building rate.

Cargo storage policy is another area that deserves attention. For instance, a different storage policy at the racking system could lead to a different forklift utilization rate. If a randomized storage policy were implemented, it could cause high cargo searching time during the retrieval process. This can impair the efficiency of the equipment utilization as well as the efficiency of the overall material flow system. On the other hand, due to the space limitation at racking systems, a dedicated storage policy is impractical. Thus, to reduce cargo searching time, while maintaining feasibility, we introduce a class-based storage policy. We use the AutoMOD simulation model to analyze the impact of this storage policy, so that a comprehensive solution can be identified.

The aim of our study is to develop a framework, which is in the form of simulation modeling approach (i.e., developed in AutoMOD environment), to examine current practices, to identify the critical key variables (e.g., the optimal number of forklifts, the skid-building skid) and to evaluate newly proposed working policies (e.g., truck dock allocation policy, cargo storage policy), which can be used to improve the overall import operations within the terminal. In this project, we study the overall material flow system of an air cargo terminal, in which the layout of the terminal, the material handling system and the dynamic behavior of the forklifts' movements and the interaction effects among the forklifts, which are difficult to model, are simulated in our model. This enhances the study of the actual terminal operations and in our simulation model the newly suggested policies could be tested in a realistic manner.

1.3 Scope

A typical air cargo terminal can consist of many types of material flow systems. It needs to handle flows of livestock, perishable cargo, dangerous goods, and general cargo such as newspaper, electronic part, electrical consumer product, home appliance item, packaging goods, clothes, motors, etc. We have opted for the general cargo flow as our main study as it has the highest percentage (i.e., > 70%) of cargo volume and its material flow being diverse is generally regarded as the most complicated, while cargo flows such as flows for perishable cargo and livestock involving dedicated material handling systems are considered to be more straightforward.

1.4 Outline of the Study

The next section provides a review of the technical literature on terminal operations for both sea port and air cargo terminal operations. Section 3 describes the simulation model structure, the method of generating input data and also the underlying assumptions. Section 4 presents the results of simulation experiments. Section 5 makes the conclusions and presents the practical recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Both sea and air cargo terminals play an active role in the flow of trade and goods from country to country. The development of good cargo terminals can serve as an impetus to the economic growth of a country such as Singapore. In order to be a competitive logistics hub, the efficiency of the terminal operations must be enhanced. However, both sea and air cargo terminals are complex material flow systems. Although many authors put their efforts in building up simulation models to study the complex seaport operations, the efforts to study air cargo operations are relatively less. The papers related to these researches are reviewed in the next sections.

2.2 Simulation of Sea Port Operations

As mentioned earlier, enormous literature on container port operations can be found. For instance, Shabayek and Yeung (2002) discussed an application of a simulation model using Witness software to simulate Hong Kong's Kwai Chung container terminals. They developed a simulation model to analyze the performance of the Kwai Chung container terminals.

Tugcu (1983) described an evaluation approach using simulation to determine a minimum total cost plan for Istanbul Seaport. The analysis covered most of the important components of a port system such as quay length, quay cranes, and warehouse. The article involved an account of a simulation study undertaken to determine the best investment plan and the best investment for Istanbul Seaport.

Shayam and Ghotb (2002) investigated the impact of different container handling techniques to the performance of a sea terminal by using computer simulation. Taylor II was chosen as the simulation software. The paper showed the role of computer simulation in evaluating the performance of a container terminal in relation to its handling techniques and their impact on the capacity of a terminal. The authors used the simulation results to propose an operational method that reduced the port terminal congestion and increased the capacity of the terminal.

Chung et al. (1988) had identified the transtainer's operation as the bottleneck in the material flow during the loading operation and suggested a simulation model to evaluate a few test strategies that could reduce the unproductive movements of the transtainer. The research paper proposed the idea of utilizing a buffer area as a method to reduce unnecessary transtainer movements during the actual loading operation. The simulation model was used to investigate the effect of this buffer area on the port's operation.

Tahar and Hussain (2000) discussed the key issues of the application of modeling and simulation for the management of the Malaysian Kelang Port. Complexity of the different seaport operations often results in difficulties in using analytical tools as a method of investigation. Hence, the authors developed a computer simulation model to analyze and design the seaport. The simulation was carried out using Arena software. The authors asserted that the developed simulation model could now also be used by the port management to improve the different operations and to make decisions on plant modification or expanding the various activities. Using simulation together with the output analysis assists the port officers in identifying a good operating strategy for logistics planning for port operations.

Dasgupta and Ghosh (2000) suggested combining both simulation approach and simultaneous equations estimation approach to study the port system of Calcutta, India. From their study, they realized that the authorities could reduce the turnaround time by simply raising prices without any change to facility configurations, and in the process, they would enjoy higher profits as well. This is mainly due to a trustworthy simulation model which offers extra insight and good estimation.

Among the important seaport parameters are the ship traffic pattern, ship sizes and types, the amount of cargo transferred relative to the carrying capacity of the ship, the number of units and sizes of loading/unloading equipment provided by the harbor, etc. Hansen (1972) performed a numerical simulation to study the sensitivity of these parameters.

Yun and Choi (1999) proposed a simulation model to do the container terminal system analysis. They used SIMPLE++, an object oriented simulation software, to develop the simulation model which is a reduced system of a real terminal in Pusan, Korea.

2.3 Simulation of Air Cargo Terminal Operations

On the other hand, the study of terminal operations in air cargo seems to be limited although the requirements and the processes are very much different from container port operations. Most of the literature on air cargo operations has been focusing on the utilization of the automated storage system. Luk (1990) used the AutoMOD simulation program to evaluate a growth plan which included large investment to build a new terminal in HACTL. Different storage systems which are highly automated such as bulk storage system (BSS) and container storage system (CSS) were included in the study.

Oudheusden and Boey (1994) considered the performance of the AS/RS as an alternative storage system in a Thai Airways Cargo terminal in order to solve the problem of insufficient space in the terminal.

Delorme et al. (1992) described a simulation study of air cargo operations and processes of a combination carrier air cargo hub. The authors studied the arrival rate of the airlines, the short connecting times for shipments at airline hubs, cargo pallet break bulk and build up operations. They also included the optimization routine to determine the best allocation of cargo tractor drivers (called runner) to transport ULD to and from aircraft.

Although Delorme et al. outlined the study of combination Carrier Air Cargo Hub, they focused mainly on the transshipment cargoes and also the operations which are “outside” of the cargo terminal such as dispatching of cargoes from aircraft to airport, traveling distance for the cargo tractor, etc. The authors had considered the time required for ULD breakdown and also the delay caused by the ULD built-up in the simulation model but many important factors for the material flow “inside” the terminal such as the capacity of storage space, the availability of workstations, the size of the terminal, the layout of the terminal are left out in the study.

In contrast to the papers reviewed, in this thesis, the entire material flow system and the interaction effects among the ground handling activities within an air cargo terminal are studied. We develop a simulation model using AutoMOD to evaluate the service level of an air cargo import terminal. Instead of focusing on the storage system, the model simulates the whole activities involving cargo flow process from the retrieval activities to the hand-over activities to the consignees or freight forwarders.

CHAPTER 3: MODELING APPROACH

3.1 The Simulation Model - Overview

We have identified two main cargo process flows (see Section 1.2):

(i) *Incoming ULD◊ Break bulk◊ Storage◊ Retrieval◊ Skid-building◊ Ship out*

(ii) *Incoming ULD◊ Break bulk◊ Retrieval◊ Skid-building◊ Ship out*

The main structure of the simulation model is built according to these key cargo process flows.

The overall efficiency of this material flow system is measured by the average cycle time. Cycle time is defined as the duration between the cargo agent's job request time (per airway bill) and the end of delivery time, where **request time** is the time that cargo agents ask for their cargo, and **end of delivery** time is the time when they have completed the skid-building and checking jobs.

The total time required by a cargo agent at a truck dock can be calculated directly by summing up the average cycle times of the jobs within a cargo agent's request. This can be done since each cargo agent is served by one dedicated forklift for cargo retrieval.

Since this duration depends heavily on the efficiency of the retrieval process by the ground handler and also the efficiency of the skid-building process by the cargo agents at truck docks, these two processes are simulated in the model.

In the development of a simulation model of an air cargo import terminal, it is unavoidable to have simplifying assumptions to restrict the complexity of the material flow system. Besides, the assumptions are also partly due to the high difficulty in collecting enough data. The first assumption is that cargo weight is used as a surrogate indicator for the cargo size, since we have observed a strong correlation between cargo size and cargo weight. Second, we assume that the forklifts move in a rectilinear manner. This is a reasonable assumption because the forklifts' movement space is narrow. Third, the average number of ULDs is assumed to be a function of aircraft size. For example, big aircraft would carry a higher number of ULDs than small aircraft. Fourth, all the forklift drivers are assumed to possess the same level of skills in controlling the forklifts. In other words, the slow down of forklifts will not be affected by other human factors. The reason to support this assumption is mainly because all the forklift drivers employed are highly skillful and experienced. Fifth, missing cargo and damaged cargo are not considered in the model as these cases are rare.

There are two stages in building a simulation model in AutoMOD. At the first stage, we design the vehicle movement systems and the queuing systems, while at the second stage we carefully define the logic of the simulation processes. The vehicle movement systems here refer to the forklift movement paths and the roller movement systems which represent the workstations, where the ULD is broken loose. In our project, these systems are modeled as a path mover system, a material handling system in which vehicles or people move along a guide path, carrying loads from pickup locations to delivery locations.

To build these systems, we have to create guide paths with proper length and direction and to place cargo loading and unloading points for each storage system, truck dock and workstation deck. Then, we have defined the vehicle type, its capacity, its loading and unloading time, its forward speed, its turning speed and also the number of vehicles required. Whilst these path movement systems are considered to be the dynamic entities of the model, the queuing systems are considered as the static entities of the model. Those entities which are modeled as queuing systems will be storage systems, truck docks, workstation decks, and the area near the workstations decks.

At the second stage, what should be given the most careful attention is the key cargo process flow. In the model, the key entities are cargoes; these are modeled as loads under the AutoMOD environment. Every load would go through either one of the two material flow paths as illustrated earlier. To simulate this material flow system, several process modules are required: receiving, break bulk, storage, cross docking, retrieval, skid-building and return trip.

3.2 The Simulation Model - Material Flow Processes

3.2.1 Receiving

Receiving is the process of load generation for the simulation. Loads are modeled in the form of unit load devices (ULDs). This process simulates the incoming ULDs that arrive at the import terminal. In addition, in this stage, we generate the input data for the simulation model. The information includes number of ULDs, number of airway bills

(AWBs), cargo weight, cargo pieces, cargo agent type, cargo agent's request time, and cargo storage location.

Generation of Unit Load Devices (ULDs)

The timing for the generation of ULDs will depend on the flight arrival schedule comprising flight arrival time, aircraft type and flight number. The arrival pattern of the flights defines the frequency of ULD arrival. There can be different arrival patterns based on time of day. In this project, the flight arrival schedule is a weekly schedule and the total number of loads to be generated at flight arrival time depends on the aircraft type (with an appropriate distribution).

Generation of Number of Airway Bills (AWBs)

We expect a proven correlation between the number of distinct AWB numbers and the number of ULDs. Generally, the higher the number of ULDs is generated, the higher the number of distinct AWB numbers will be. Thus, a change in the number of ULDs would be a key indicator of a change of workload in an air cargo terminal. However, this relationship is not straightforward, as the same AWB number can exist in more than one ULD. Therefore, we propose a nonlinear regression model called Poisson Regression to model the relationship between the predicted average number of distinct AWBs and the number of ULDs.

Some commonly used functions for Poisson Regression are shown below.

(i) $\mu = X\beta$

(ii) $\mu = \exp(X\beta)$

(iii) $\mu = \text{Log}_e(X\beta)$

where μ = The dependent variable

β = The independent variable

X = The coefficient

It is understood that in fact there are many statistical tools such as SPSS, Statgraphics, etc are available to test the Poisson Regression Model. In this project, Statgraphics is used to test all the above functions. We figure out the factor and the dependent variable for each function. For example, for function $\mu = \text{Log}_e(X\beta)$, μ or the number of airway bill becomes the dependent variable while number of ULDs is the independent variable. Then, the collected empirical data are input into Statgraphics.

To select the best-fitted function, we carry out many statistical analyses in the Statgraphics. The selection is based on Analysis of Deviance and Residual Analysis.

Table 1: Analysis of Deviance for Poisson Regression Model

Analysis of Deviance			
Source	Deviance	Df	P-Value
Model	320.859	1	0.0000
Residual	125.378	30	0.0000
Total (corr.)	446.237	31	

Table 1 shows that the results of fitting a Poisson regression model have successfully describes the relationship between the number of airway bills and the number of ULDs. Since the P-value for the model in the Analysis of Deviance table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The results tabulated in Table 1 is for the equation of the fitted model, which is

NumAWB = exp(0.754077 + 0.974821*Log_e_NumULD)

where **NumAWB** = Number of Airway bill

NumULD = Number of Unit Load Device

The predicted mean number of AWBs is then used as the input parameter for a Poisson distribution to generate the number of unique AWB numbers. In other words, μ is used as the mean parameter for the Poisson distribution. To model the fact that cargo stored in different ULDs can have the same AWB number, we construct an empirical distribution from the observed data, which is presented in Figure 1.

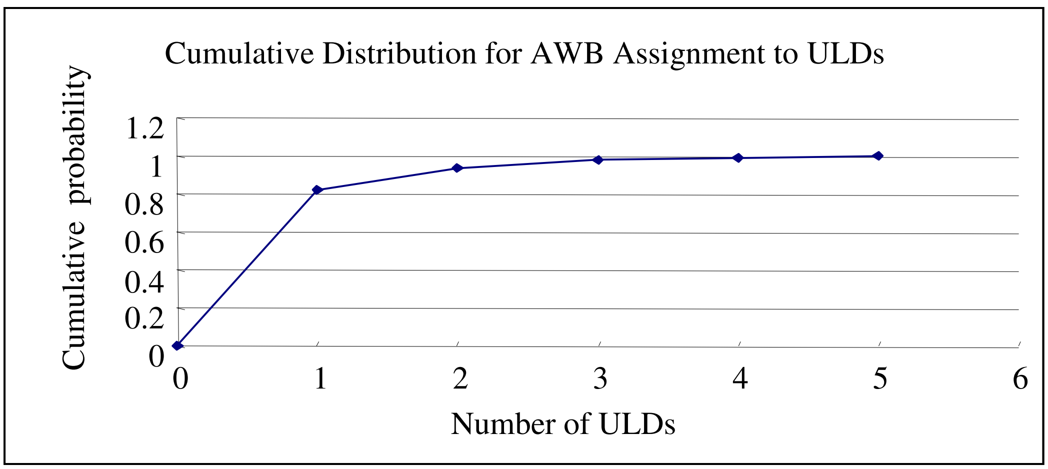


Figure 1: Cumulative Distribution for AWB Assignment to ULD

Based on this empirical distribution, we assign to each distinct AWB number an attribute signifying the number of ULD's that contain cargo for that AWB, subject to the following constraint:

$$\text{NumULD} - \sum_i (i-1) * N_i > 0,$$

where NumULD = number of ULDs, $\boldsymbol{N_i}$ = the total number of distinct AWBs with cargo stored in i ULDs (for i = 1, 2, 3, …, m; $\boldsymbol{m}$ wherein is determined from the actual observations). This requirement ensures that there is remaining ULD space to allow the remaining cargoes to mix with other AWB's cargoes. The reason for having this constraint is further explained in the following example: Assume that cargo with the AWB number 00213421 has been stored in two ULDs (ULD numbers 5411 and 5412). Generally, one of the ULDs (say 5412) will be fully occupied by the AWB's cargo. The cargo in the second ULD (5411) would have AWB 00213421's cargo but this ULD might also contain other cargo from other AWBs. In other words, ULD 5412 has cargo from just one AWB (and is called a Single AWB ULD), while ULD 5411 might have cargo from more than one AWB (and is called a Mixed Loading ULD). So, it is certainly possible for both ULDs to have AWB number 00213421's cargoes.

On completion of this step, the cargo for each distinct AWB number is then allocated into a certain number of ULDs according to previously assigned attribute (see algorithm 1.0 in Appendix).

Generation of Cargo Weight and Cargo Storage Location

To capture the cargo mix within a ULD, additional distributions or data are required (see Figure 2-6). The distributions are either empirical distributions which are defined directly by the data or the likely distribution obtained through Arena analyzer. Using these distributions, different AWB's will be labeled with different cargo characteristics such as cargo weight.

Cargo weight determines the storage system of the cargo. In the process of generation of the cargo weight information, the total weight of a ULD is generated first. Although the range of the ULD weight is wide, fortunately, there is an obvious upper bound. According to the International Air Transport Association (IATA) standard, every ULD has its maximum size and allowable maximum weight limit. These limits result in an upper bound weight value, which also can be observed from the actual data. As for each AWB's cargo weight attrib ute, a probabilistic method (see algorithm 2.0 in Appendix) is used to generate different cargo weight values and then assign them to each AWB number within a ULD.

During the break bulk process, each ULD might consist of several AWB numbers with different attributes that need to be broken down into small loose cargo. Each piece of loose cargo is then assigned to a different storage location. However, it has been found that in reality some of the light but large pieces of cargo might need to be stored in the PCHS instead of the AS/RS. Thus, to determine the storage location for each loose cargo, weight information alone is insufficient. One of the most satisfactory ways to handle this difficulty is to use a probabilistic method and loose cargo with low cargo weight is given a lower probability of being stored in the PCHS than small loose cargo with high cargo weight. In other words, there is still a chance for low cargo weight items to be stored in the PCHS. These considerations highlight the need to further deepen the statistical analysis to the level of studying each cargo weight profile at each storage system as shown in Figures 2-4.

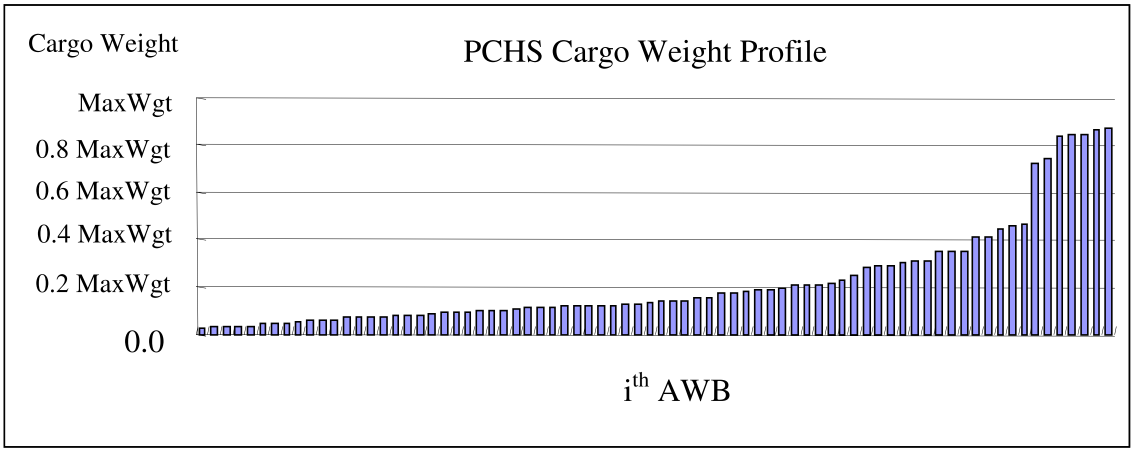


Figure 2: PCHS Cargo Weight Profile

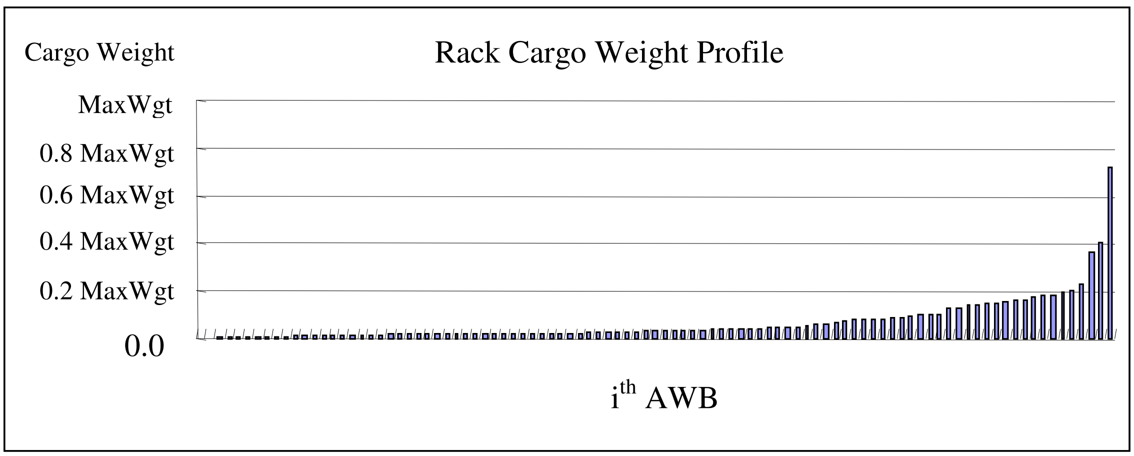


Figure 3: Rack Cargo Weight Profile

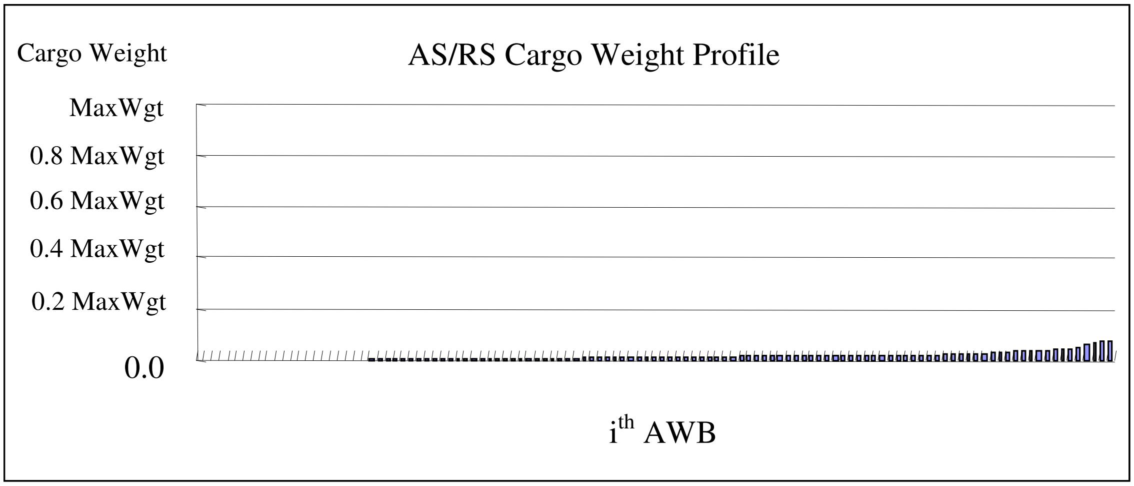


Figure 4: AS/RS Cargo Weight Profile

Although most of the heavy cargo is stored at PCHS, the result shows that there are still low weight cargoes stored at PCHS. This is mainly due to the low density cargo, which is light but big in size. Certainly, this type of cargo needs to be stored at PCHS as it is too big to be fitted into an AS/RS bin size.

Apart from this, we also have done data analyses on the actual data and the statistics show considerable evidence suggesting that the quantity of low weight cargo stored at the AS/RS surpasses the amount of light weight cargo stored at PCHS and racks. As a result, data analyses have been conducted separately on these three different types of storage systems (PCHS, AS/RS and racks); the probability data can be calculated from these analyses is shown in Table 2. We can observe that the selection of particular storage location for each cargo item will depend on the related cargo's weight and the probability data as demonstrated in Table 2.

Table 2: Probability Data for Storage Locations Assignments

Cargo Weight Range	%	P(PCHS)	P(Racks)	P(AS/RS)	Total
W<=100	0.4831	0.0070	0.3706	0.6224	1
100<w<=200	0.1351	0.1500	0.3500	0.5000	1
200<w<=400	0.1182	0.2000	0.5714	0.2286	1
400<w<=600	0.0507	0.5333	0.4667		1
600<w<=800	0.0642	0.6316	0.3684		1
800<w<=1000	0.0304	0.5556	0.4444		1
1000<w<=2000	0.0811	0.8333	0.1667		1
2000<w	0.0372	1.0000			1

To elaborate, Table 2 indicates that for those cargoes' weight less than or equal to 100 kg, the probability of storing the cargo at AS/RS is much higher than the rest of the storage systems. This observation would seem to suggest that most of the light weight cargo (e.g., cargo weight < 100 kg) is small in size. However, when the cargo weight increases, the probability of storing the cargo at the AS/RS decreases while the chance of storing cargo in the PCHS or at the racks increases. This condition will continue until to a level where the probability of storing cargo in the PCHS still continues to increase but the probability of storing cargo at the racks starts to decline. This indicates that when a certain cargo size limit has been exceeded, the heavy cargo cannot be put into racking systems anymore and the PCHS becomes the only appropriate storage system.

Generation of Cargo Agent Type and Cargo Agent's Request Time

Based upon the statistical information, we can divide cargo agents into two categories – big cargo agents and small cargo agents. Big cargo agents are mostly the big logistics service providers, while small cargo agents could be walk-in individuals as well as small freight forwarders. Such distinctions are further broken down by cargo agents' request time. There is a clear distinction in request time behavior between the big and small cargo agents as summarized in Figures 5-6. The big cargo agents come to the terminal frequently, as they have to handle a larger amount of cargo than the small cargo agents.

It is crucial to know that there is a significant time interval in between the flight arrival time and the time for cargo ready to be collected by cargo agent (i.e., cargo request time). Upon the arrival of a flight, the cargo in the form of ULD needs to be retrieved from the inner part of the aircraft body. It is then placed at ramp side (i.e., area near to the aircraft parking lot) before it is towed to air cargo import terminal. However, this takes time since it needs to wait for a tractor, which is the only main transport equipment for ULDs in between the ramp area and the cargo terminal. Upon the ULDs arrival at the terminal, ULDs need to be broken down into loose cargo before it can be distributed out. However, due to the resource constraint, they might need to be put aside first at the terminal while waiting for resources such as roller, workstation and manpower for break bulk.

After break bulk, the loose cargo may need to wait for forklift in order to be transported to truck dock. Similar to other resources, the forklifts may not be available all the time as the forklifts could be occupied by other cargoes. All these workflows explain why the duration between flight arrival time and request time is of the magnitude of hours. In fact this is a classical challenge faced by all the ground handlers in terms of material flow efficiency. Therefore, the ground handler encourages cargo agents to come to the air cargo terminal only after several hours of the flight arrival time instead of the exact flight arrival time.

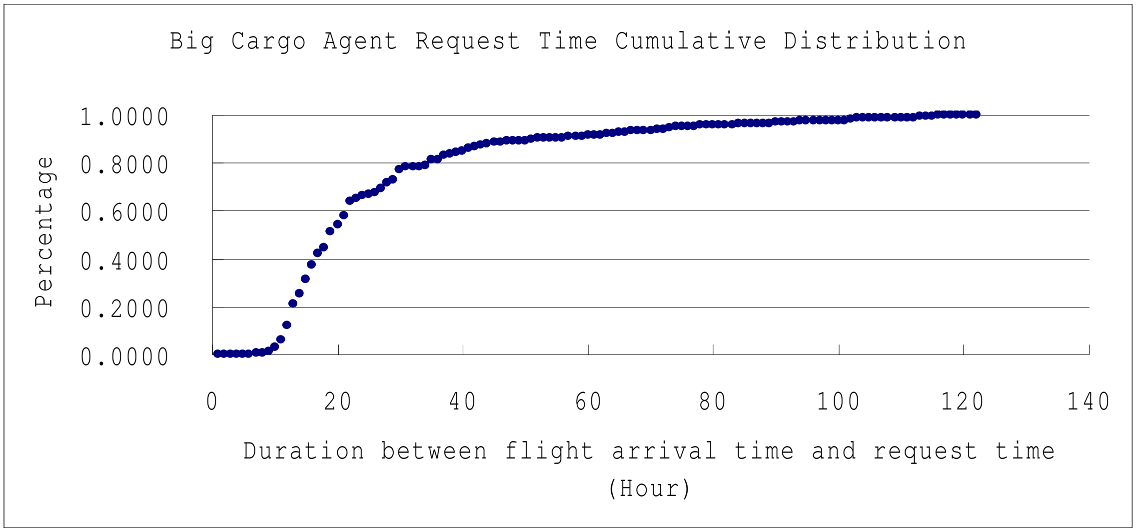


Figure 5: Big Cargo Agent Request Time Cumulative Distribution

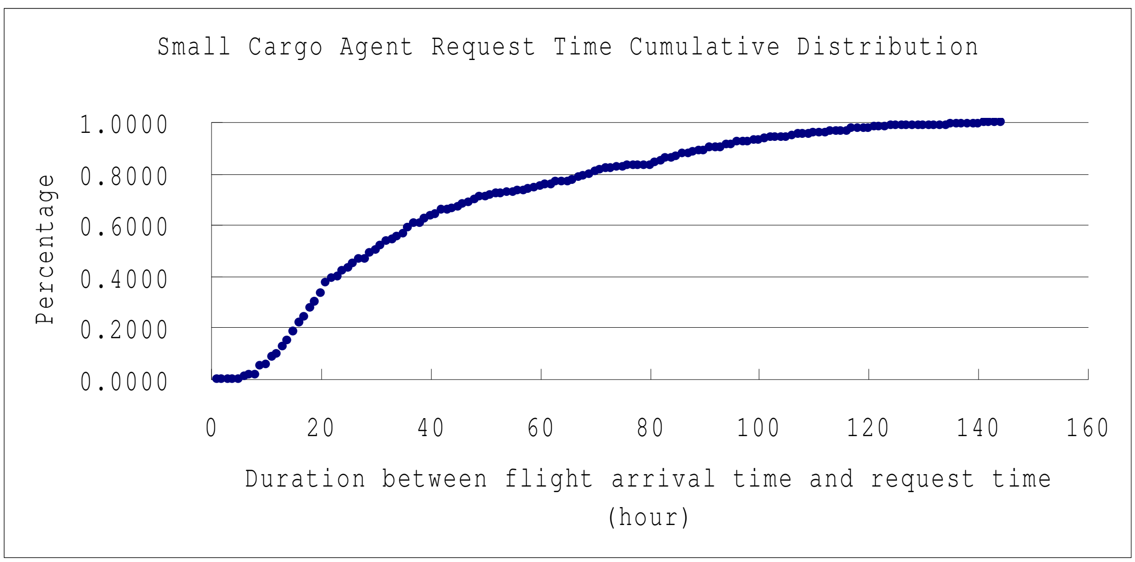


Figure 6: Small Cargo Agent Request Time Cumulative Distribution

After assigning all the necessary information, all the ULDs are stored in the PCHS Queue. The whole receiving process is summarized in Figures 7-8.

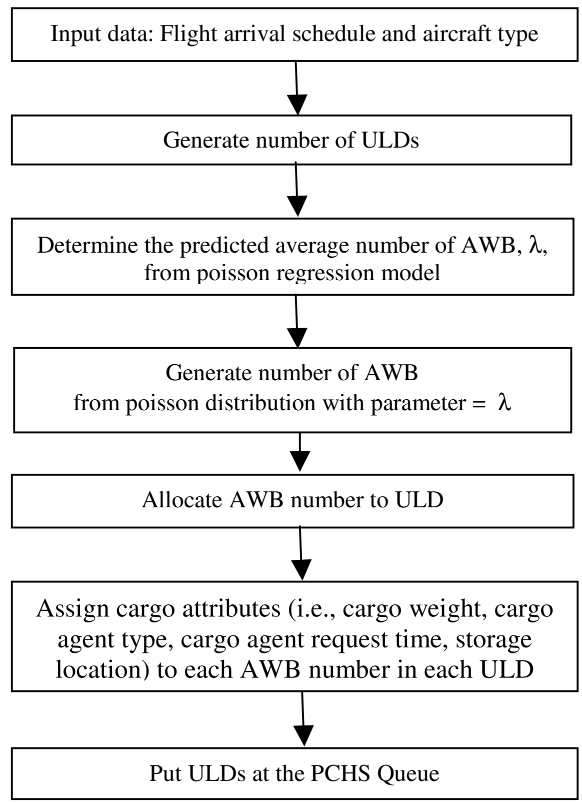


Figure 7: Flow Chart for Receiving Stage

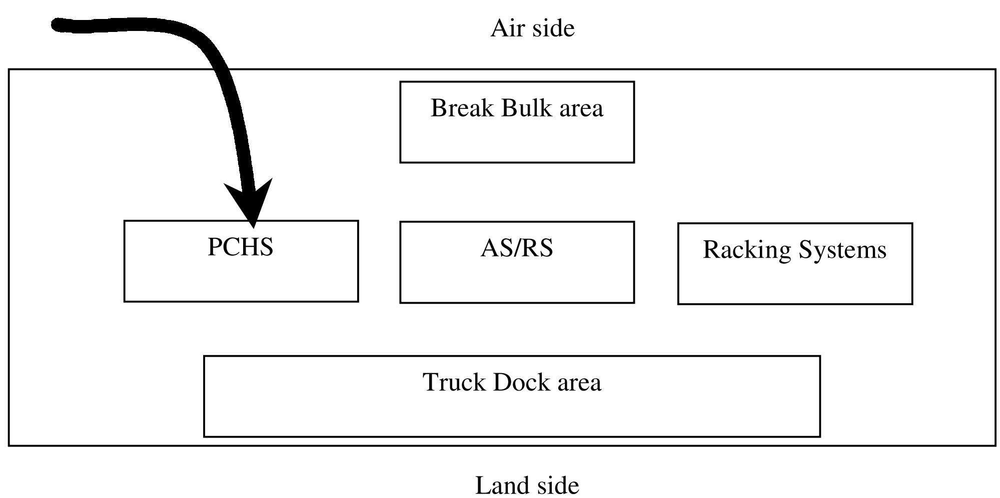


Figure 8: Material Flow Direction for Receiving Stage

3.2.2 Break bulk

"Single AWB" ULDs (where all the cargo inside the same ULD belongs to the same cargo agent) are not sent for break bulk but continue to stay in the PCHS until requested by the related freight forwarder. Otherwise, all newly arrival ULDs need to go through the break bulk process (see Figures 9-10). From the simulation's perspective, break bulk is actually a process of allocation of previously generated information or attributes of a ULD load to small, loose cargo. Graphically, it is also a process of converting the ULD load into several smaller loose cargo loads. The type of loose cargo is determined by its storage location attribute. If workstation space is available and roller equipment is free, then the incoming ULDs can be sent to workstation's decks for break bulk. A break bulk processing time is then randomly generated from a distribution to represent the delay in sending cargo to the storage area or truck dock.

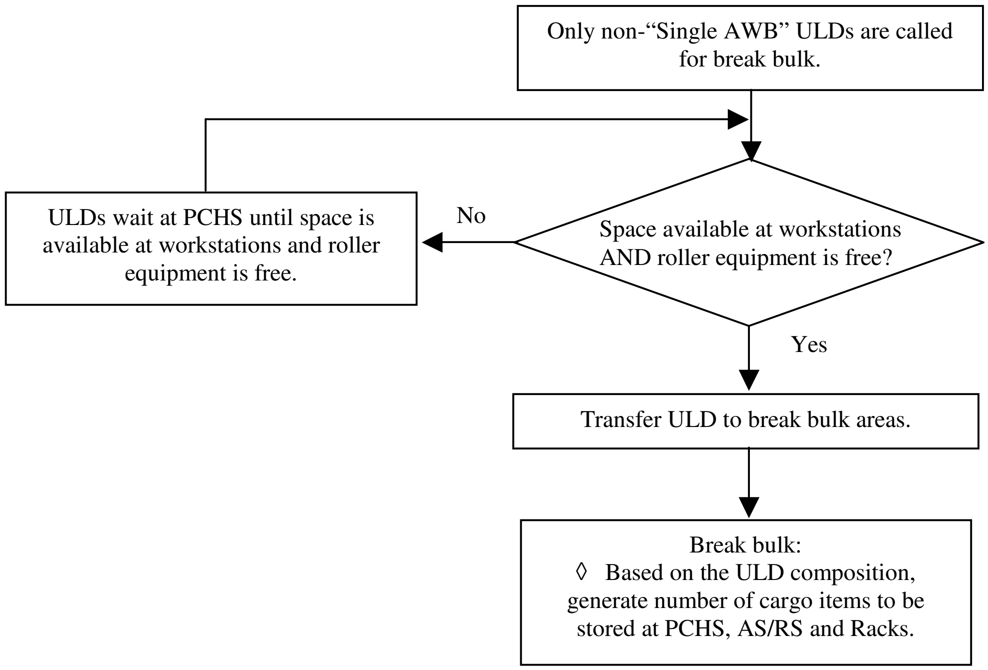


Figure 9: Flow Chart for Break Bulk Stage

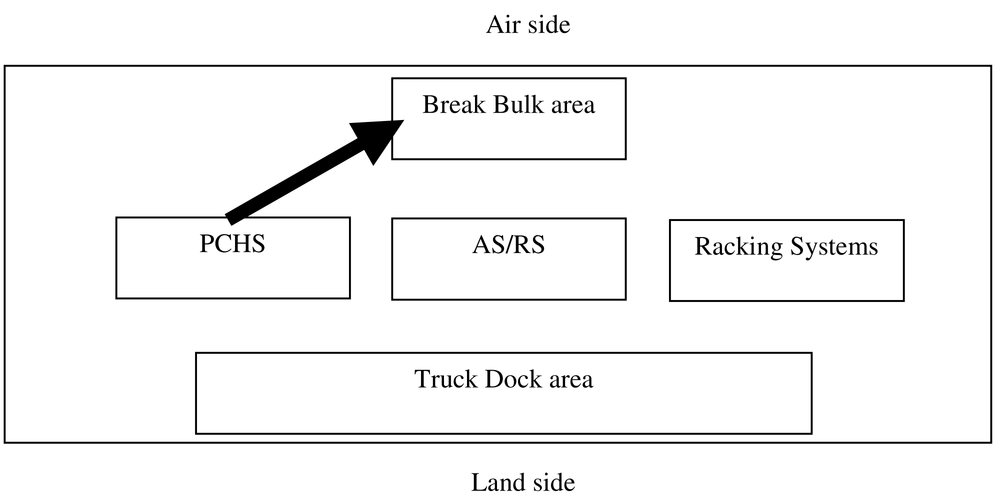


Figure 10: Material Flow Direction for Break Bulk Stage

3.2.3 Storage and Cross docking

After break bulk, two possible scenarios can occur: 1) The loads are directly transferred to the truck dock without intermediate storage (the so-called cross docking process). 2) The loads are transferred to the respective storage systems for temporary storage while waiting for cargo agents to come to collect; this is simulated in a storage process module (see Figures 11-12).

Based upon the attributes of each load generated in the previous process, the storage location as well as the cargo agent's request time can be identified. This triggers the forklift to implement the storage or cross docking process. Although the terminal is similar to a traditional warehouse, there are some cross docking opportunities in the terminal that stem from the possibility that a cargo agent arrives at the truck dock while a ULD with his cargo is being broken loose. The storage and cross docking process flow is shown in the Figure 11.

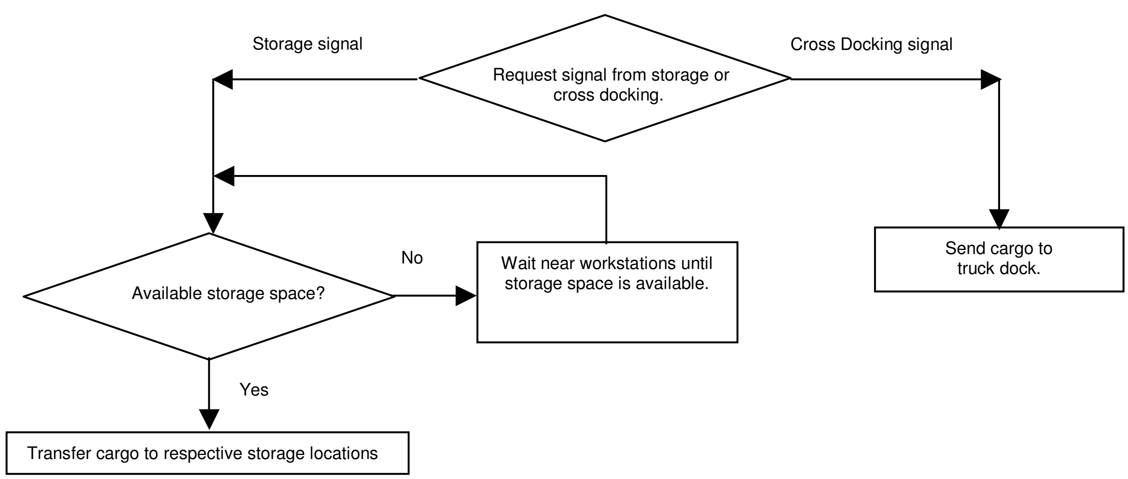


Figure 11: Flow Chart for Storage and Cross Docking Stage

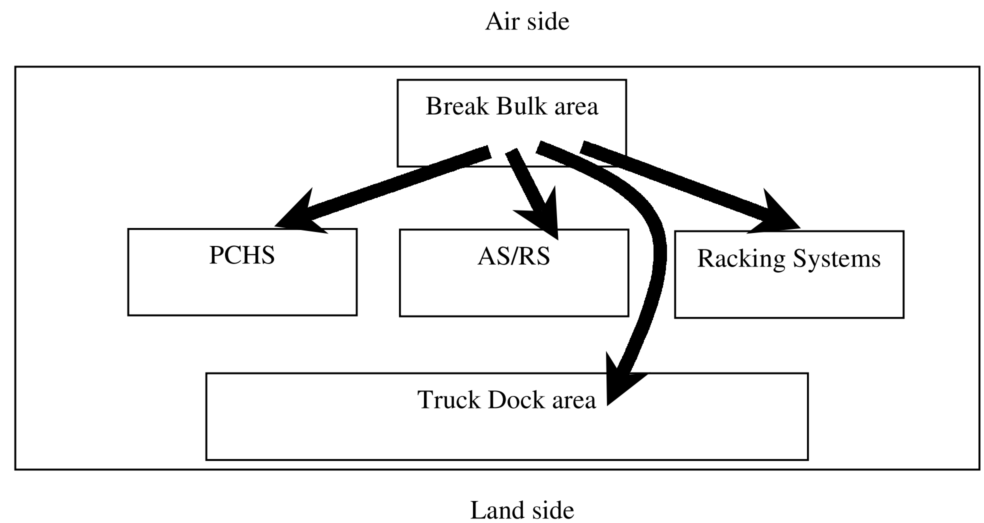


Figure 12: Material Flow Direction for Storage and Cross Docking Stage

3.2.4 Retrieval and Skid-building

In the retrieval process, forklifts are called to retrieve cargo from storage locations (AS/RS, PCHS or racks) and transfer it to the truck dock. Once cargo is unloaded at the truck dock, skid-building activities commence. The total occupancy time of the truck dock depends on the number of cargo pieces and the skid-building rate.

<u>*Generation of Cargo Piece*</u>

Cargo-pieces information is vital for the simulation model, as it can affect the total time required for a cargo agent to occupy a truck dock. The higher the number of pieces of cargo, the more time is required to finish the skid-building and checking jobs. The number of pieces of cargo is significantly different among the different storage systems (PCHS, racks and AS/RS). We use three separate empirical distributions of cargo-pieces (see Figures 13-15) to capture this feature.

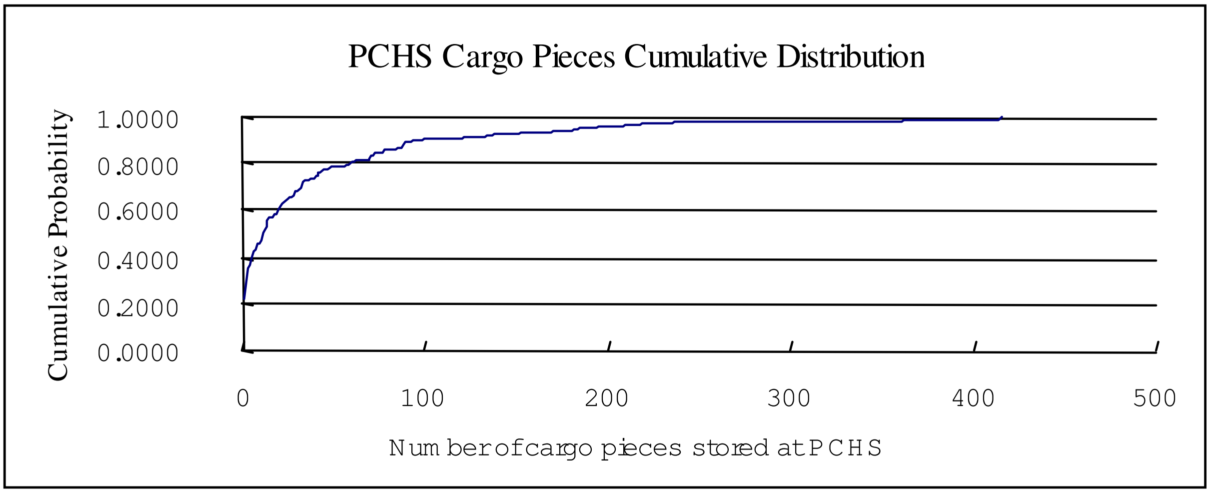


Figure 13: PCHS Cargo Pieces Cumulative Distribution

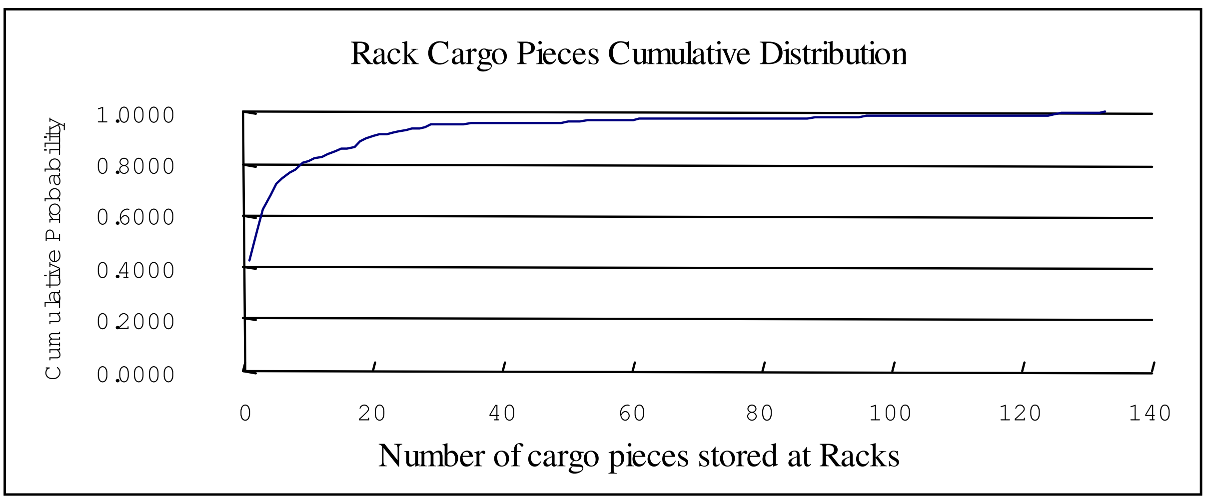


Figure 14: Rack Cargo Pieces Cumulative Distribution

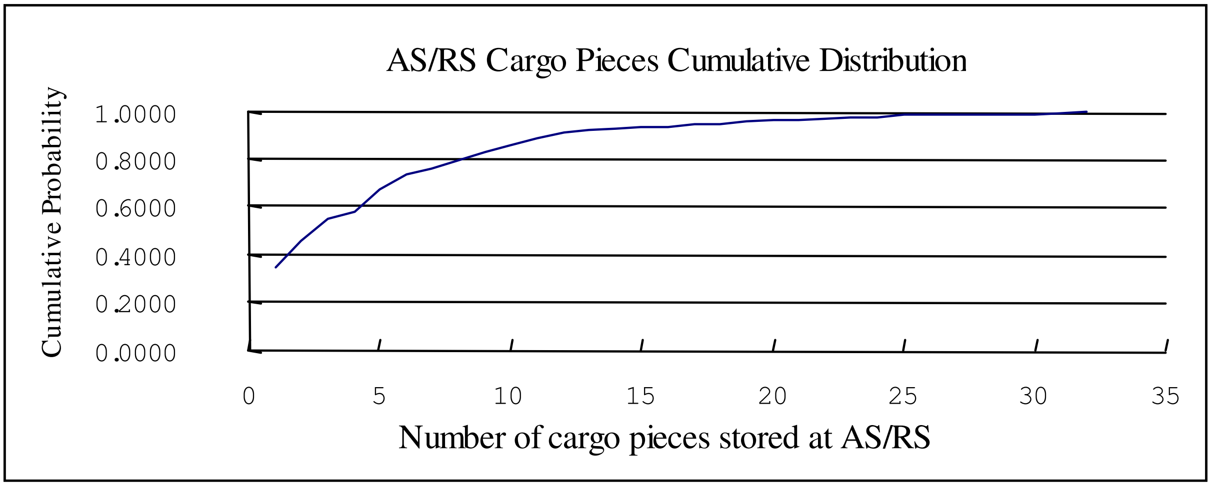


Figure 15: AS/RS Cargo Pieces Cumulative Distribution

Other than cargo pieces which can affect the total time required for the skid-building process, skid-building rate is another key factor. The skid-building rate is heavily dependant on the way cargo agents are doing their jobs, as well as the size of the cargo to be handled. We have arrived at an estimate of the average skid-building rate through a time study conducted on the actual operations. The retrieval and Skid-building process flow is shown in the Figures 16-17.

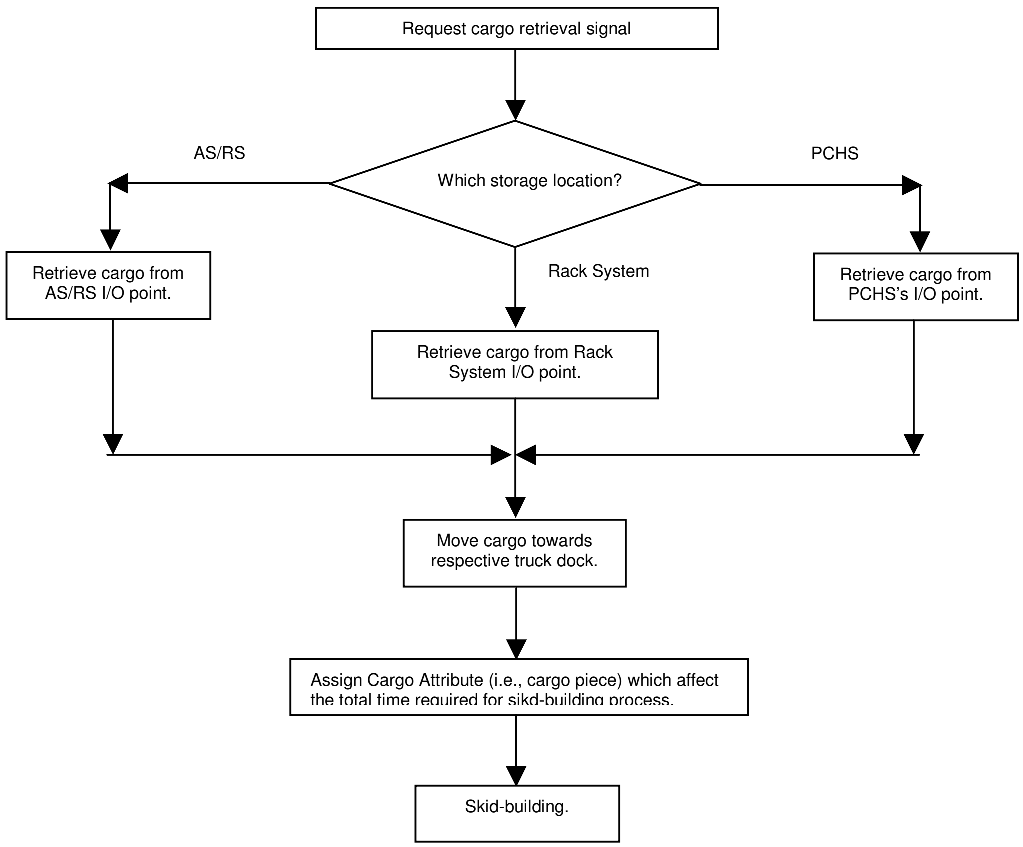


Figure 16: Flow Chart for Retrieval and Skid-building Stage

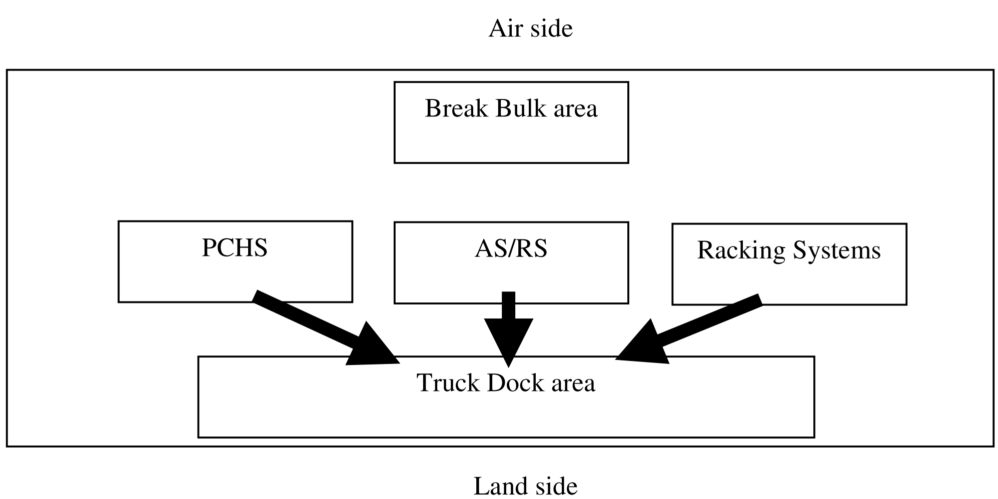


Figure 17: Material Flow Direction for Retrieval Stage

3.2.5 Return Trip

After completion of skid-building and checking jobs, the empty container or pallet is left behind at the truck dock. Again, forklifts are required to clear the truck dock space by removing the empty container/pallet back to the PCHS. Likewise, the AS/RS bin will also be sent back to the AS/RS by forklifts after the requested cargo has been retrieved from the bin. As illustrated previously, the storage process and the retrieval process also require forklifts; all these processes use the same path mover system and the same batch of forklifts. Thus, all these can affect the forklift utilization rate and also the traffic conditions within the import terminal. In particular, there will be an interaction effect among the forklifts; the delay of the forklifts in meeting demand can be simulated in the model. This can help us to study the impact of these interaction effects on the terminal's overall performance.

To improve the terminal's operations, we have identified four potential areas which are described in detail in the next sections. These four areas are:

i. Number of forklifts

ii. Clustering policy

iii. Convenient rule

iv. Skid-building Rate

3.3 Number of Forklifts

The forklift is one of the most important equipment used for cargo storage retrieval operations within the terminal. They are used to transfer cargoes from workstations to storage locations, from workstations to truck docks, and from storage locations to truck docks. The impact of the number of forklifts on the terminal's service level becomes significant during the peak hour. This is primarily due to the considerable friction and the interaction among the forklifts and this situation is likely to occur when a lot of storage and retrieval jobs happen during the busy hour.

One of the advantages of building this simulation model is to simulate the interaction effects among the forklifts, which could directly affect the terminal's performance level. Due to the terminal's space constraint, we can no longer presume that the increase of number of forklifts could lead to a better service level as the interaction effects among the forklifts could slow down their movements within the terminal. Additionally, at a different level of cargo volume, the optimal number of forklifts could change. Whilst it is often difficult to use mathematical models to study these, all these could be evaluated through simulation.

3.4 Clustering Policy

There has been an attempt to study the working practice in the terminal. Learning to select the right storage policy in racking systems can help to reduce the cargo searching time at the rack areas. It appears that there are two possible ways to implement a dedicated storage policy in the terminal. This includes the cargo-agent based storage policy and the airline based storage policy. However, the nature of the limited space in racking systems inhibits the implementation of the dedicated storage policy. Hence, a randomized storage policy is used by the operator. Although this policy could save a lot of storage space, it displays a long cargo searching time. Thus, a potentially noteworthy policy called clustering (or class-based) storage policy is recommended.

The clustering policy is a compromising strategy that divides the storage area into a small number of sub-areas, where each sub-area is dedicated to storing cargo belonging to a particular class.

Since the number of cargo agents is higher than the number of airlines, an airline class based storage policy is preferred. Due to space limitation, the rack areas are divided into just two storage areas for the purpose of clustering. An analytical clustering model which can be used for any number of clusters is built to decide the members of each cluster as shown below.

Let

$\boldsymbol{f_{jq}}$ = Cargo units to be stored in racks for airline j during time interval $\boldsymbol{q}$

N = The total number of airlines.

$\boldsymbol{p}$ = number of clusters

$$\boldsymbol{y_j} = \begin{cases} 1 & \text{If airline } j \text{ is chosen as the cluster median.} \\ 0 & \text{Otherwise} \end{cases}$$

$$\boldsymbol{x_{ij}} = \begin{cases} 1 & \text{If airline } i \text{ is chosen to join the cluster } j\text{.} \\ 0 & \text{Otherwise} \end{cases}$$

z_j = Amount of rack storage space allocated to cluster median j.

Objective Function: Min $\sum_{j} z_j$

Subject to:

$$z_j \geq \sum_{i} f_{iq} x_{ij} \qquad \forall q \quad \forall j$$

$$\sum_{j} x_{ij} = 1 \qquad \forall i$$

$$\sum_{j} y_j = p$$

$$x_{ij} \leq y_j \qquad \forall i \quad \forall j$$

$$x_{jj} \geq y_j \qquad \forall j$$

$$x_{ij} \in \{0,1\} \qquad \forall i \quad \forall j$$

$$p \in R^+ \text{ and } p \bullet 1$$

If $p = 1$, then it is equivalent to the random storage policy; if $1 < p <$ N, then it means the policy will cluster a few airlines together; if $p =$ N, it means one dedicated storage location is allocated to one airline. Here, we choose $p = 2$ as the space is limited and inadequate to be allocated for a higher number of clusters.

Normally, the number of airlines of the air cargo terminal is not huge and the model is tractable. For example, the Memphis International Airport (i.e., the busiest airport with 39 airlines and 3.39 million tonnages in the year of 2003; information from Airports Council International) has less than 50 airlines and the size of the i and j is therefore less than 50.

In our study, C-plex is used to solve the model. From the C-plex result, two airlines are chosen to be the cluster median (i.e., $y_j = 1$) and its cluster members can be identified from the result $x_{ij} = 1$. These results show the selected cluster medians and cluster member for us to implement the policy.

3.5 Convenience Rule

It would be beneficial to assign cargo agents to truck docks near to the storage locations of their cargo. For example, truck docks near the AS/RS area would be a good assignment for cargo agents with most of their cargo stored in the AS/RS. Similarly, truck docks near the PCHS would be a good assignment for cargo agents with most of their cargo stored at the PCHS. Generally, the traveling distance between truck docks and storage area is a good measurement of convenience. Hence, the convenience of a truck dock depends on the distance between the location of truck dock and the storage locations. In an example as shown in Figure 18, the truck dock number 10 is the nearest truck dock to the storage system S1 and therefore the cargo agent should be assigned to this truck dock if this cargo is stored at S1. In case when the truck dock number 10 is occupied, the truck dock number 9 shall be the second choice.

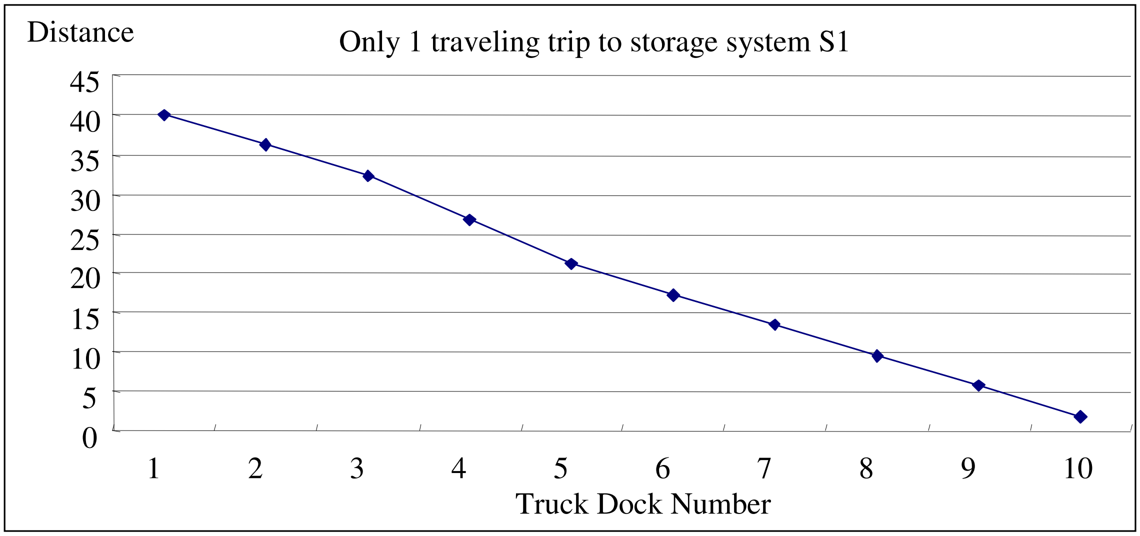


Figure 18: The Most Convenient Truck Dock for Cargo Stored at Storage System S1.

When there is a storage system S2 located far away from the truck dock number 10 but near to the truck dock number 1, the convenience profile becomes entirely different for those cargo stored at the storage system S2 as depicted in Figure 19. It shows that the truck dock number 1 is the most convenient truck dock as its traveling distance is the shortest.

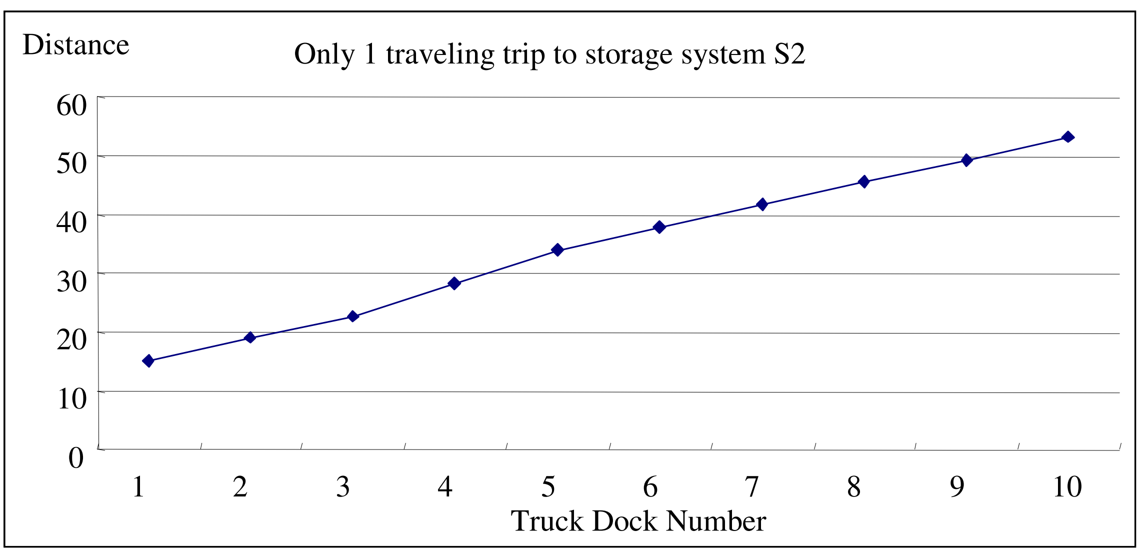


Figure 19: The Most Convenient Truck Dock for Cargo Stored at Storage System S2

All the aforesaid examples are restricted to the case where each request has only one particular airway bill's cargo. The combination of the above two conditions can complicate the convenience profile. Figure 20 depicts the new convenience profile in which the best choice of truck dock should be the truck dock number 6 or 7 as these locations allow the forklifts to move in a minimum distance to retrieve cargoes from two different storage systems S1 and S2.

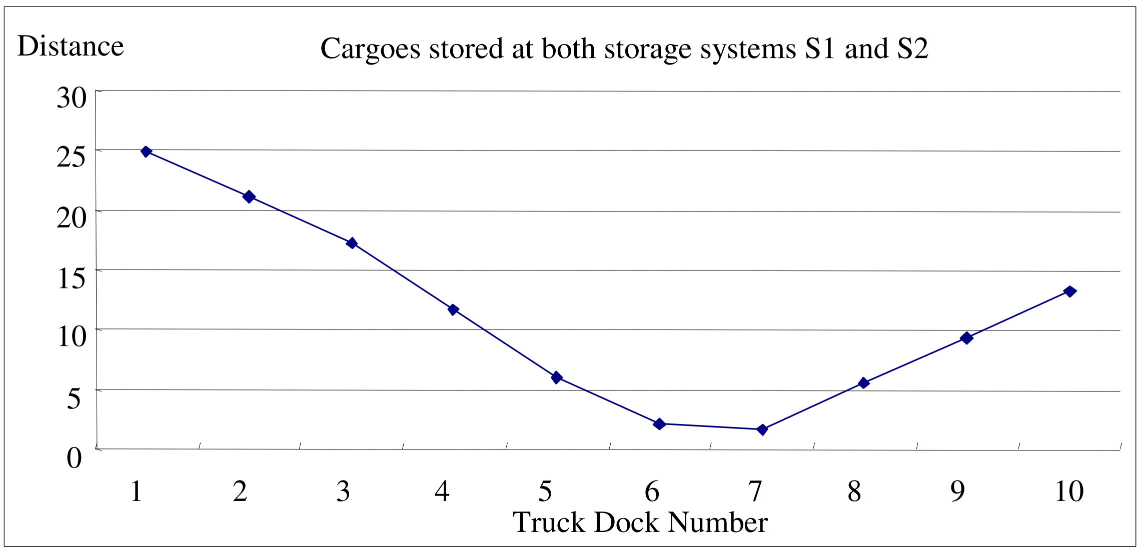


Figure 20: The Convenient Truck Dock for Cargoes Stored at Both Storage Systems S1 and S2.

The purpose of the above illustrations is to emphasize on the rationale behind of the truck dock selection in order to reduce cargo retrieval time under different convenient profile. In fact, it is just a matter of minimizing the total traveling distance between the truck docks and storage locations. The lesser the retrieval time, the shorter the waiting time required for a cargo agent. This improves the material flow efficiency within the terminal. Of interest is to note that the cargo retrieval time can be reduced if the movement of a forklift is smooth and efficient. This could be done through the reduction of the interactions among the forklifts. A forklift can affect other forklift when they come near together. The interaction slows down each other. Low interaction among the forklifts also means less traffic congestion. Ultimately, this would not only improve the discharge rate of the terminal but at the same time it secures a better safety level in the terminal. One way to achieve all these is to use a proper truck dock assignment policy.

The convenient profile can change further if the number of trips to storage systems S1 and S2 are more than one. This complication can become extreme when the number of storage system increases. In the actual operations, most of the cargo agent's cargoes are stored in several different storage systems and locations. This is most particularly true for those big cargo agents. Different cargo agents have different demand profiles. Cargoes can be stored at different locations such as automated storage/retrieval system (AS/RS), racking system or floor goods area (FG), pallet/container holding system (PCHS), etc. Because of the facility layout, some of the truck dock locations are near to PCHS and some of the truck dock locations might be near to FG. Different truck dock location under different cargo agent demand patterns influence the traffic condition within the terminal differently. In short, the facility layout and the cargo agent demand pattern impact the traffic condition. No doubt most of the time neither we can change the facility layout nor we can alter the cargo agent demand pattern, a proper truck dock assignment is still the potential area to reduce the forklift traveling time between the truck dock and cargo storage zone. Consistency in applying this proper assignment may even alleviate forklift congestions within the terminal.

To study a truck dock assignment policy, we analyze the relationship between the truck dock location and the forklift traffic condition within the terminal. We design an analytical approach to understand how a truck dock location can affect traffic condition in every single forklift pathway within a cargo terminal. Congestion will normally set in when the density of certain path exceeds a critical level. Because of the congestion, the travel time between truck docks and storage locations becomes longer. In other words, the path's density could affect the overall traveling time of a forklift. Certainly, the layout of the terminal, the cargo agent demand profile and the truck dock assignment practice are among the main contributors to a path's density.

To Analyze a Truck Dock Assignment Policy

To conduct a traffic study in the terminal, we need to identify all the "pathways" within the terminal. Next, we capture the frequency of forklifts passing through every pathway under a given cargo agent demand pattern. All these are illustrated in details in the following study. We use a small cargo terminal to simplify the illustration. The cargo terminal consists of four truck docks, one pallet/container holding system (PCHS), one floor goods area (FG), one automated storage/retrieval system (AS/RS), one staging area (SA), and one workstation area (WS). As for the manpower, there are only four truck dock operation assistants and four forklift drivers.

We use a segmentation method to identify all the forklift pathways. By using a set of nodes and arcs, the areas for forklifts' movement are segmented as shown in Figures 21-

22. The arcs are the pathways for forklifts while nodes represent input/output (I/O) points of the paths. There are altogether thirteen paths, which are selected for the study. The numbering of the paths is shown in Figures 21-22. After the segmentation, the calculation of the frequency for forklifts passing through a particular path becomes possible.

To highlight the effects of different assignments we construct two scenarios (Scenario 1 and Scenario 2). Both scenarios have the same cargo agent demand pattern. However, the truck docks being assigned to cargo agents are different. These two scenarios are shown in Table 3 and 4. In the first scenario (i.e., Scenario 1), a cargo agent having cargo stored at the PCHS has been assigned to truck dock number 1. Truck dock number 2 is allocated to a cargo agent with cargoes stored at three separate locations, namely PCHS, FG, and AS/RS. As for truck dock number 3, the related cargo agent needs to collect cargoes from FG and AS/RS. The last truck dock number 4 is assigned to a cargo agent having a similar demand pattern with the truck dock number 2's cargo agent.

Table 3: Truck Dock Assignment Pattern in Scenario 1

Scenario 1	
Truck dock number.	Cargo agent demand pattern
1	1 PCHS
2	1 PCHS; 1 FG; 1 AS/RS
3	1 FG; 1 AS/RS
4	1 PCHS; 1 FG; 1 AS/RS

In the second scenario, as a whole everything is the same as the Scenario 1 except the truck dock assignment is different.

Table 4: Truck Dock Assignment Pattern in Scenario 2

Scenario 2	
Truck dock number	Cargo agent demand pattern
1	1 FG; 1 AS/RS
2	1 PCHS; 1 FG; 1 AS/RS
3	1 PCHS; 1 FG; 1 AS/RS
4	1 PCHS

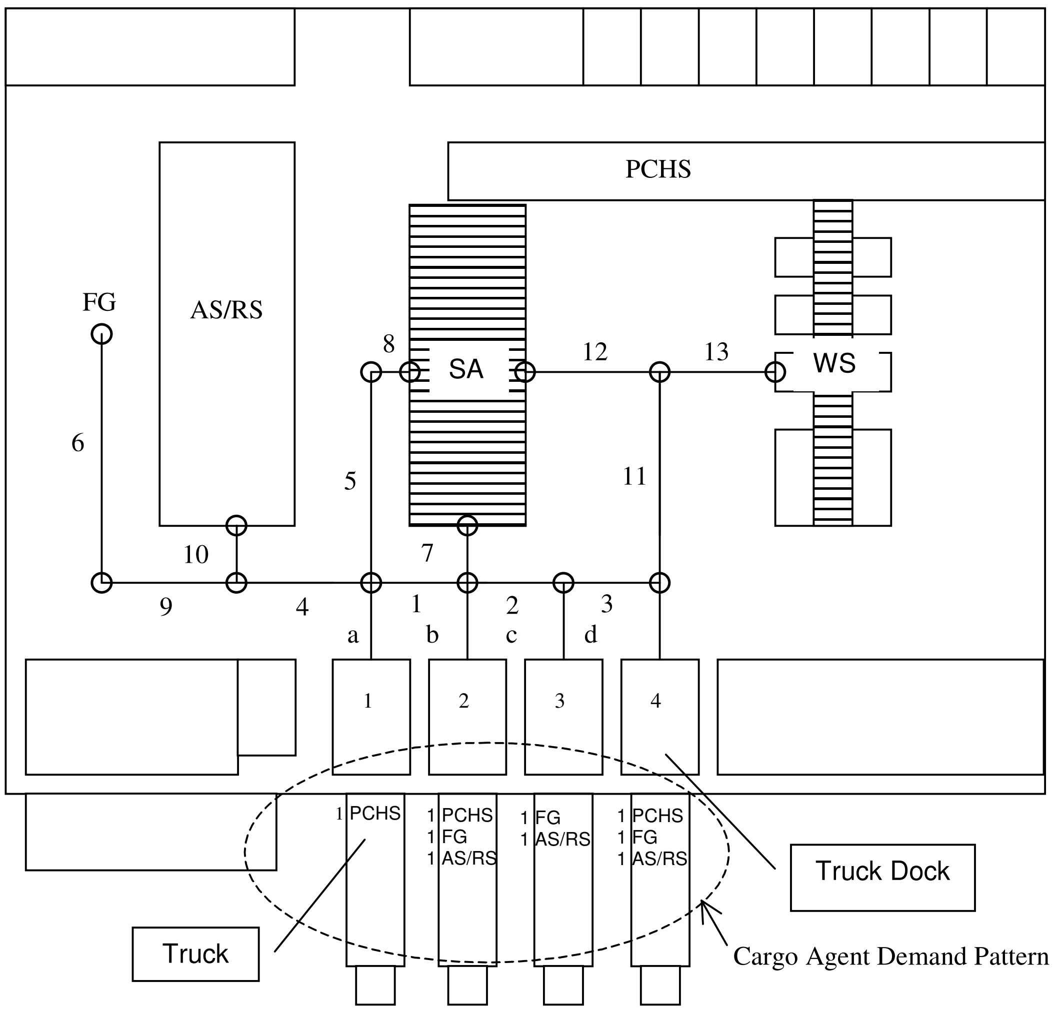


Figure 21: The Truck Dock Assignment in Scenario 1

Based on Scenario 1, when the cargo agent at truck dock number 1 wants to retrieve cargo from PCHS, the forklift must travel through path 1, path 2, path 3, path 11 and path 13 to reach workstation WS. To transport the PCHS cargo from WS to truck dock number 1, again the forklift will be required to travel the same route in the reverse sequence that is path 13, path 11, path 3, path 2 and finally path 1. This condition is different for the cargo agent at truck dock number 2. Although the cargo agent needs to retrieve cargo from the same PCHS storage location, the forklift needs not to travel through path 1. This implies that the forklift travels in a shorter distance than the previous forklift. As a result, we can use this basic approach to check and to note down all the traveling paths by all the forklifts in between the truck docks and the storage locations. Having successfully taken down all the routes, we can tabulate the results into Table 5.

Table 5: The Routing Pattern for Scenario 1

Scenario 1		
Truck Dock No.	Paths	No. of paths
1	a → 1 → 2 → 3 → 11 → 13 → WS → 13 → 11 → 3 → 2 → 1 → a	10
2	b → 2 → 3 → 11 → 13 → WS → 13 → 11 → 3 → 2 → b b → 1 → 4 → 9 → 6 → FG → 6 → 9 → 4 → 1 → b b → 1 → 4 → 10 → AS/RS → 10 → 4 → 1 → b	8 8 6
3	c → 2 → 1 → 4 → 9 → 6 → FG → 6 → 9 → 4 → 1 → 2 → c c → 2 → 1 → 4 → 10 → AS/RS → 10 → 4 → 1 → 2 → c	10 8
4	d → 11 → 13 → WS → 13 → 11 → d d → 3 → 2 → 1 → 4 → 9 → 6 → FG → 6 → 9 → 4 → 1 → 2 → 3 → d d → 3 → 2 → 1 → 4 → 10 → AS/RS → 10 → 4 → 1 → 2 → 3 → d	4 12 10
	Total:	76

Looking at these routes traveled, we can figure out the frequency of a path being passed through by the forklifts. For instance, the number of times that the forklifts pass through path 1 is 14. This approach has been working very well in calculating the frequency of the forklifts in others paths too. By knowing the frequency, we can calculate the traveling distance as well. Table 6 shows the results.

Table 6: The Overall Traveling Distance in Scenario 1

Path *i*	Distance (m)	Number of times that path *i* being occupied by forklift	Total traveling distance (m)
1	3.5	14	49
2	3.5	12	42
3	3.5	8	28
4	4.8	12	57.6
5	7	-	0
6	8.8	6	52.8
7	2.2	-	0
8	1.3	-	0
9	4.8	6	28.8
10	2.2	6	13.2
11	7.8	6	46.8
12	4.8	-	0
13	4.4	6	26.4
Total traveling distance			**344.6**

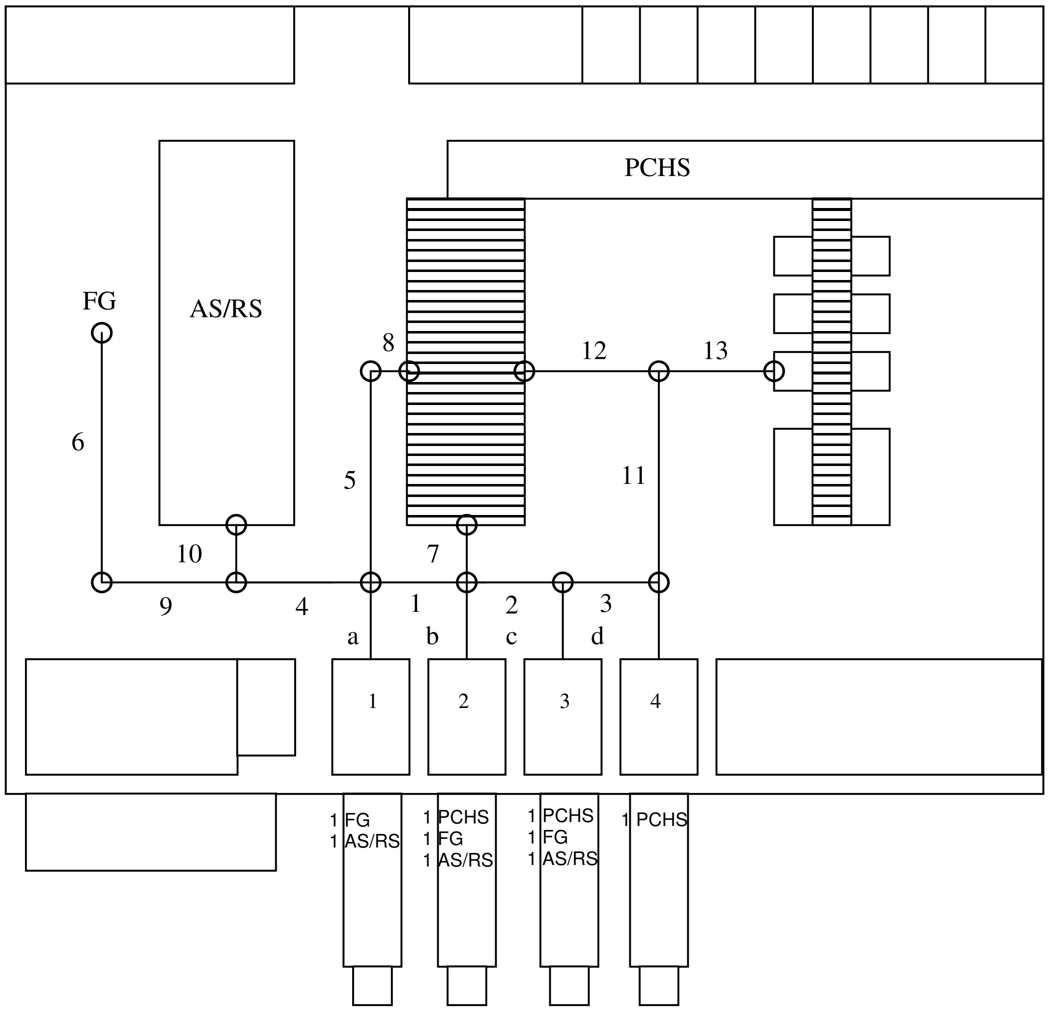


Figure 22: The Truck Dock Assignment in Scenario 2

When the same approach is implemented to Scenario 2, we obtain another set of information as summarized in the Table 7 and 8.

Table 7: The Routing Pattern for Scenario 2

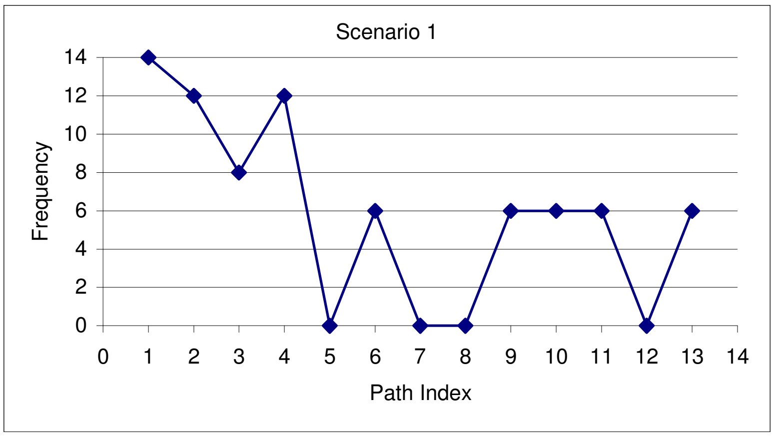
Scenario 2		
Truck Dock No.	Paths	No. of Paths
1	a → 4 → 9 → 6 → FG → 6 → 9 → 4 → a a → 4 → 10 → AS/RS → 10 → 4 → a	6 4
2	b → 2 → 3 → 11 → 13 → WS → 13 → 11 → 3 → 2 → b b → 1 → 4 → 9 → 6 → FG → 6 → 9 → 4 → 1 → b b → 1 → 4 → 10 → AS/RS → 10 → 4 → 1 → b	8 8 6
3	c → 2 → 1 → 4 → 9 → 6 → FG → 6 → 9 → 4 → 1 → 2 → c c → 2 → 1 → 4 → 10 → AS/RS → 10 → 4 → 1 → 2 → c c → 3 → 11 → 13 → WS → 13 → 11 → 3 → c	10 8 6
4	d → 11 → 13 → WS → 13 → 11 → d	4
	Total:	60

Table 8: The Overall Traveling Distance in Scenario 2

Path *i*	Distance (m)	Number of times that path *i* being occupied by forklift	Total traveling distance (m)
1	3.5	8	28
2	3.5	6	21
3	3.5	4	14
4	4.8	12	57.6
5	7	-	0
6	8.8	6	52.8
7	2.2	-	0
8	1.3	-	0
9	4.8	6	28.8
10	2.2	6	13.2
11	7.8	6	46.8
12	4.8	-	0
13	4.4	6	26.4
Total traveling distance			**288.6**

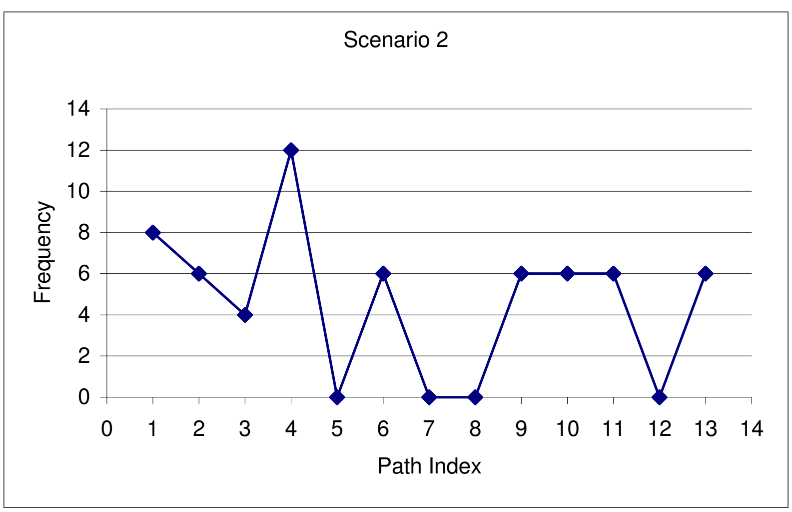
As shown in the Tables 6 and 8, the overall traveling distance for scenario 1 will be 344.6 meters, which is much longer than the overall traveling distance for scenario 2 namely 288.6 meters. The insight derived from this analysis is that a proper truck dock assignment is a potential area worth in investigating further for the ultimate improvement of the terminal's operations.

This approach also reveals the frequency of the forklift passing through each pathway. This piece of information allows us to identify the critical path and shows that a proper truck dock assignment could reduce a path density with the highest frequency. For example, the highest frequency number is 14 in Scenario 1 as compared to the 12 in Scenario 2. All these results are shown in Figures 23-24.



Path	Frequency
1	14
2	12
3	8
4	12
5	0
6	6
7	0
8	0
9	6
10	6
11	6
12	0
13	6
	76

Figure 23: The Frequency of Each Pathway in Scenario 1



Path	Frequency
1	8
2	6
3	4
4	12
5	0
6	6
7	0
8	0
9	6
10	6
11	6
12	0
13	6
	60

Figure 24: The Frequency of Each Pathway in Scenario 2

To infer further, it is so obvious that the traveling frequency of the forklifts in some of the paths (i.e., path *4*, path *6*, path *9*, path *10*, path *11* and path *13*) is totally not affected by the truck dock assignment. But, this is not true for other paths. For instance, the paths *1-3* are heavily influenced by the truck dock assignment. For those paths which are not affected by the assignment, their forklift traveling frequencies are proportional directly to the respective number of trips as below:

Forklift passing frequency for path *4*	$\propto$	No. (AS/RS + FG) trip
Forklift passing frequency for path *6* and path *9*	$\propto$	No. FG trip
Forklift passing frequency for path *10*	$\propto$	No. AS/RS trip
Forklift passing frequency for path *11* and path *13*	$\propto$	No. PCHS trip

Besides, the graphs also indicate that the path *4* possesses a very high forklift passing frequency and with the same frequency value in both scenarios. This cannot be changed unless the warehouse layout is reconfigured. In other words, the analysis also helps us to identify the bottleneck of the traffic flow within the terminal. For those paths which are affected by the assignment, their frequencies can be calculated by the following way.

If

$i = 1$ denotes truck dock *1*	$j = 1$ denotes path *1*
$i = 2$ denotes truck dock *2*	$j = 2$ denotes path *2*
$i = 3$ denotes truck dock *3*	$j = 3$ denotes path *3*
$i = 4$ denotes truck dock *4*	

then,

$$\boldsymbol{WS}_{ij} = \begin{cases} 1 & \text{If there is a trip between workstation area and truck dock } i \text{ passing through path } j. \\ 0 & \text{Otherwise} \end{cases}$$

$$\boldsymbol{ASRS}_{ij} = \begin{cases} 1 & \text{If there is a trip between AS/RS and truck dock } i \text{ passing through path } j. \\ 0 & \text{Otherwise} \end{cases}$$

$$\boldsymbol{FG}_{ij} = \begin{cases} 1 & \text{If there is a trip between floor goods} \\ 0 & \text{Otherwise} \end{cases}$$

n = number of truck docks.

The path j's forklift traveling frequency = $[\ \sum_{i=1}^{j} \boldsymbol{WS}_{ij} + \sum_{i=j+1}^{n} (\boldsymbol{ASRS}_{ij} + \boldsymbol{FG}_{ij})\ ]$

where j =1, 2, 3, …, n -1

Regardless of the layout configuration, we can adopt the same method to analyze the material flow pattern of a terminal, a warehouse or a cross docking. From the results, we are well-informed on how a truck dock assignment policy can affect the congestion level of certain pathways under a given facility layout. The most interesting part here is that this method has shown that not all the path density can be reduced through a truck dock assignment policy and it can identify the bottleneck of the congestion area in a quantitative manner.

3.6 Skid-building Rate

The total time required for a cargo agent to finish the skid-building jobs is another factor worth exploring, which can give great impact to the average cycle time. Skid-building is the main activity at the truck docks. Besides building up the cargo into a standard skid size, the cargo agent also needs to check and to confirm the cargo. As the space available at the truck dock is limited, slow skid-building rate can impair the cargo retrieval process because there might not be sufficient space for retrieved cargo to be placed at the truck dock. Indeed, skid-building rate is one of the main indicators to show the efficiency of the truck dock activities. If a cargo agent does not plan properly with the way of doing the skid-building job, then a longer period of time is required to complete the skid-building task. This certainly can give negative impact to the overall terminal's performance.

CHAPTER 4: SIMULATION ANALYSIS

We conjecture in our research that the performance of the highly mechanized terminal can be improved during the peak period by using the optimal number of forklifts (and other equipment), and by implementing the right working policies, including the appropriate storage policy and an intelligent truck dock allocation policy. Hence, an exploratory study has been conducted to examine and to verify the current peak period conditions. In addition, comparisons are made between the performance of the existing policies and the proposed policies. In identifying other possible areas of improvement, the exploratory study was also extended to examine the impact of the changes in the skid-building rate.

4.1 Verification and Validation

We used two established evaluation processes that are verification and validation to evaluate our model. The objective of verification is to find and remove bugs in the logic of the model. In our project, the verification process has two stages. The first stage of verification is to determine the input data is read correctly and the loads are assigned with all the necessary right information. The second stage of verification is to ensure the logic is correct. For instance, the load with its storage-location attribute being AS/RS will be "physically" stored at the AS/RS. One main advantage of using AutoMOD is that it provides a good visual aid, which could help us to detect logical bug directly from the animations. This enhances the verification job. Moreover, in ensuring the robustness of the model, endurance test had also been conducted. After the verification, the model was validated to insure the logic was consistent with the real processes and the assumptions made provided realistic results. In the process of validation, it is necessary to make sure the output of the models reaches an acceptable level of the real-world system being represented.

Additionally, since our model is empty at the beginning of the simulation, we have determined the amount of time the model takes to warm up until it reaches steady state. This is important for models to fill up before statistics can be gathered. This can reduce the bias of the initial conditions and be part of the efforts to prove the problem is modeled correctly.

In determining the warm up period, the mean response levels (i.e., average cycle time) are graphed according to a moving average. By viewing the warm up graphs, it is possible to identify the steady state. Based on this result, the simulation reaches steady state within fewer than five days. Hence, our warm up period is fixed as one week. In the following analysis, the data from the first week are discarded and only the data starting from the second week are collected and analyzed.

Based upon the observation and understanding of the existing terminal's condition, simulation using the models developed herein should at least indicate that:

(i) average cycle time (in the simulation) is close to the actual estimated cycle time value.

(ii) the peak hour falls into the midnight period, using the existing flight schedule.

The main performance indicator, average cycle time, was used to compare the simulation results with the actual data. In terms of percentage, the difference between the simulation average cycle time and the actual average cycle time is only 0.3798% which has validated the above point (i). This ensures that the logic was consistent with the actual key processes and to provide realistic results. As for point (ii), it will be discussed in the next section.

4.2 The Peak Hour

Based on the information collected, certain characteristics of the terminal are identified, including: the number of forklifts being used within the terminal, the average skid-building rate, the truck dock allocation policy, the incoming cargo volume, and the storage policy being implemented at the rack areas. To analyze the existing operations, all these conditions are fixed at the beginning of the simulation.

As mentioned earlier, forklifts are the main equipment used for both storage and retrieval processes. A high forklift utilization rate implies the peak period. For instance, for a period of time, if its forklift utilization exceeds 0.70 then it is considered a peak period. By investigating the forklift utilization, it is possible to figure out the peak period over the whole week.

Under the AutoMOD environment, the forklifts' activitiy can be divided into four main categories: (i) delivering, (ii) retrieving, (iii) going to park, and (iv) parking.

Each category might consist of several states. AutoMOD provides us with the following definition of the vehicle states - the current state of the vehicle corresponding to the type of job that the vehicle is undergoing. All the vehicle states are shown in Table 9.

Table 9: The Definitions of State

Category	***State***	***Definition***
Delivering	Deliver	The vehicle is traveling to the destination location of an onboard load.
Delivering	Deliver Setdown	The vehicle is setting down an onboard load.
Parking	Idle	The vehicle is parked and is not currently performing a scheduled job.
Going to Park	Move	The vehicle is traveling to a location not associated with a load.
Retrieving	Retrieve	The vehicle is traveling to the location of a claimed load.
Retrieving	Retrieve Pickup	The vehicle is picking up a claimed load.

Based on our definitions, a forklift is considered to be utilized if and only if it is engaged in either delivering or retrieving.

Through running our simulation model, we have successfully identified the peak period. Figure 25 shows that the peak period in the simulation occurs around midnight, which matches well with the actual observations.

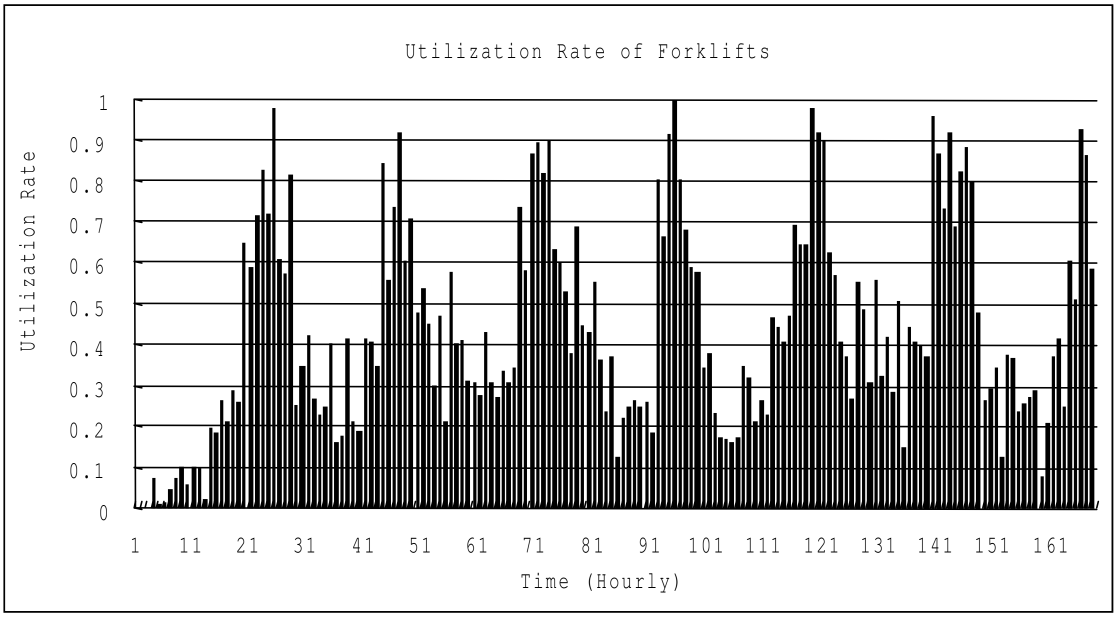


Figure 25: Utilization Rate of Forklifts for The Existing Terminal

4.3 The Evaluation of the Number Forklifts

The impact of the number of forklifts was the first topic in our sensitivity analysis. Figure 26 indicates that one forklift is unable to cope with the job demand as the forklift utilization is at the maximal rate all the time. Although there are certain down periods where the number of job requests is low or zero, the utilization rate still remains high across the whole week. This indicates that a lot of backlog was accumulated during the busy hour causing the forklift to be busy all the time.

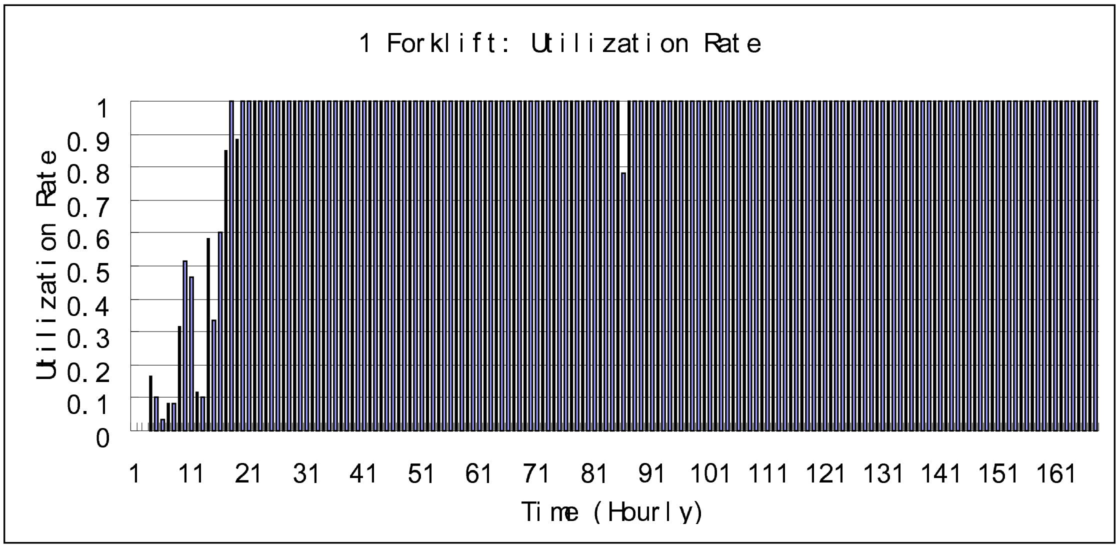


Figure 26: Utilization Rate of One Forklift

The results from Figures 27-33 exhibit the same peak period namely around 2100-0200 as the utilization rates during this period of time are relatively high as compared to other periods. This similarity is because the same flight schedule is used as the input for all these simulation runs. However, the most important point to establish here is that these results have not only shown the peak hour but also have further proven the validity of the model.

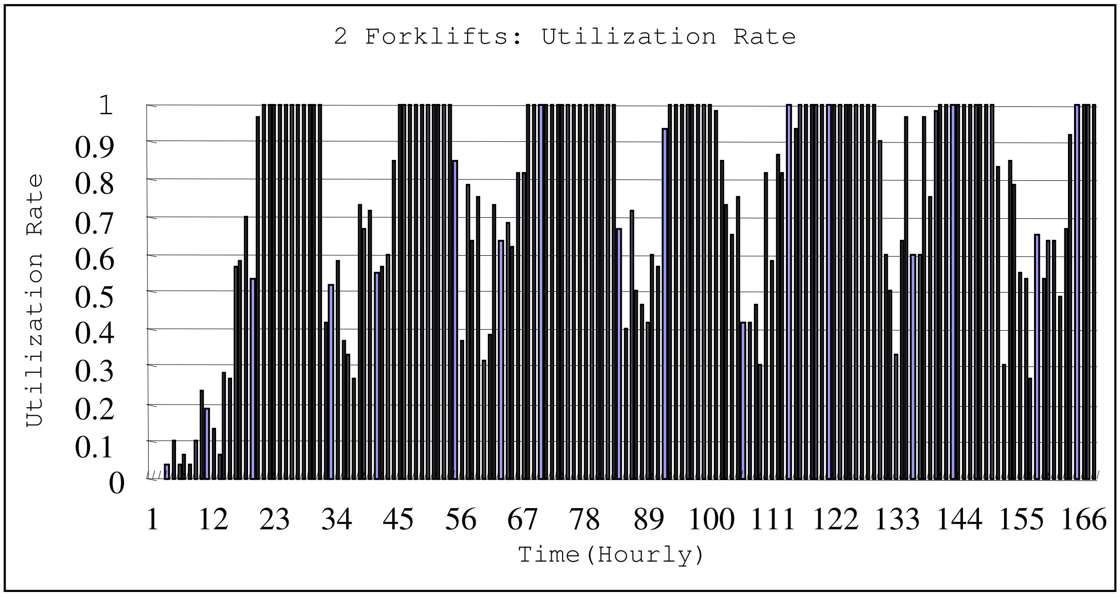


Figure 27: Utilization Rate of Two Forklifts

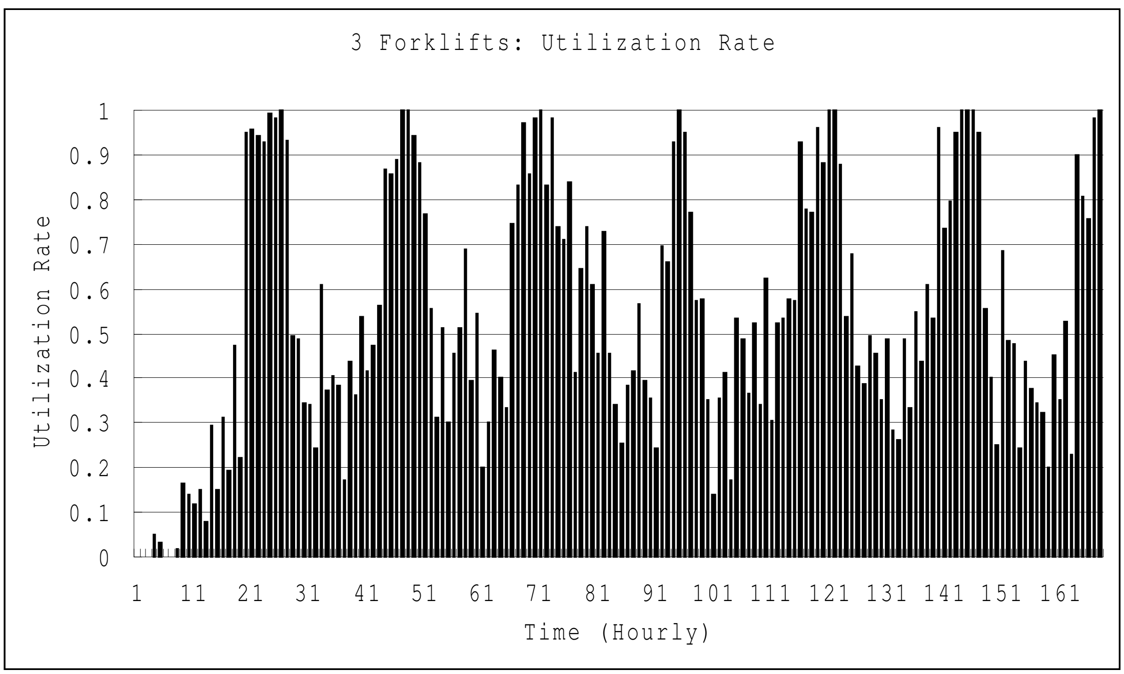


Figure 28: Utilization Rate of Three Forklifts

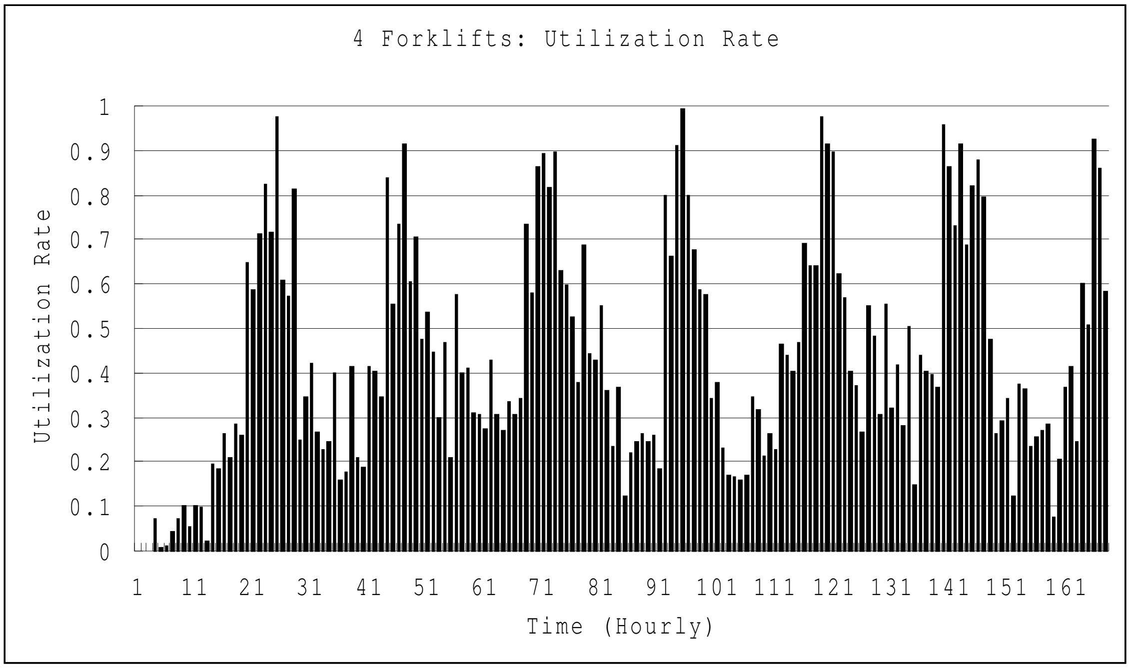


Figure 29: Utilization Rate of Four Forklifts

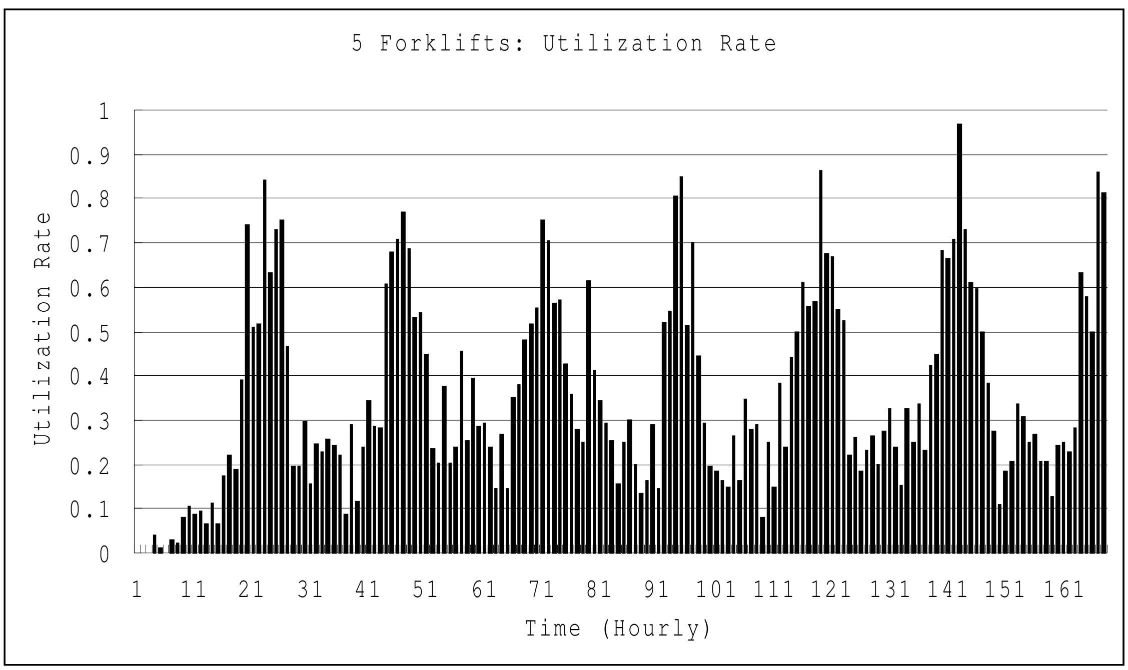


Figure 30: Utilization Rate of Five Forklifts

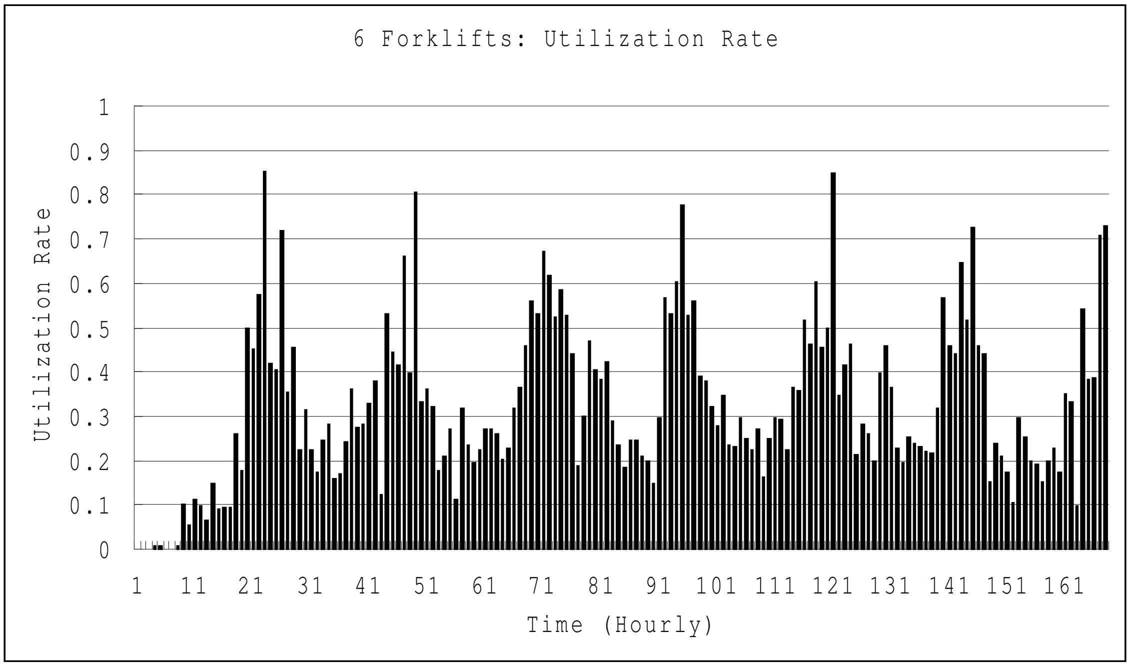


Figure 31: Utilization Rate of Six Forklifts

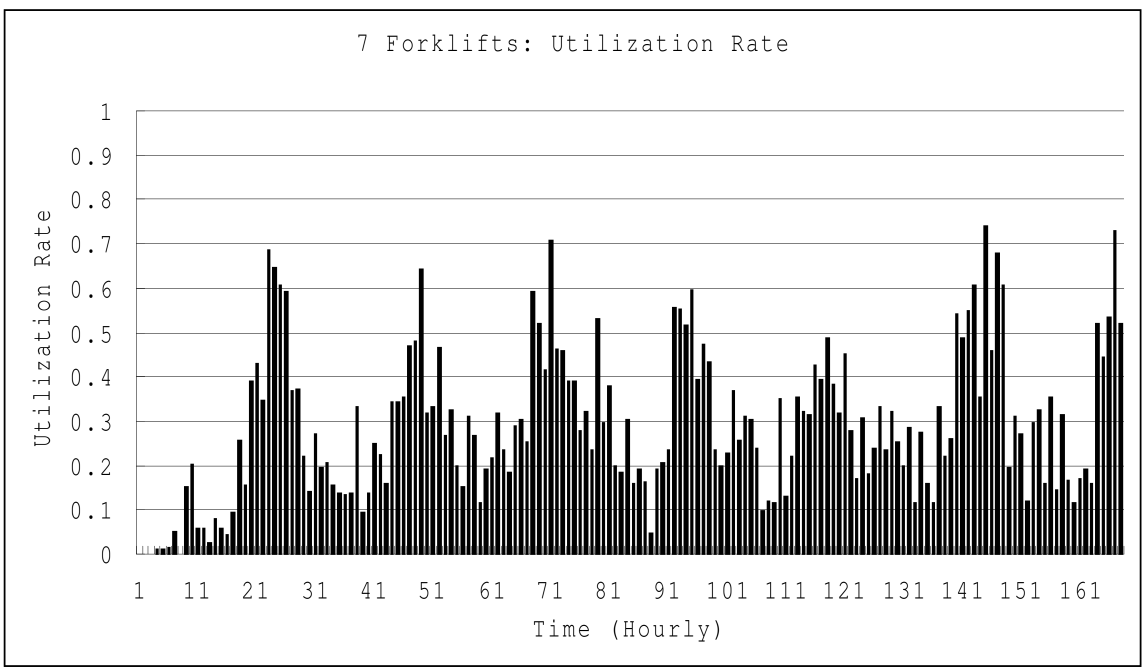


Figure 32: Utilization Rate of Seven Forklifts

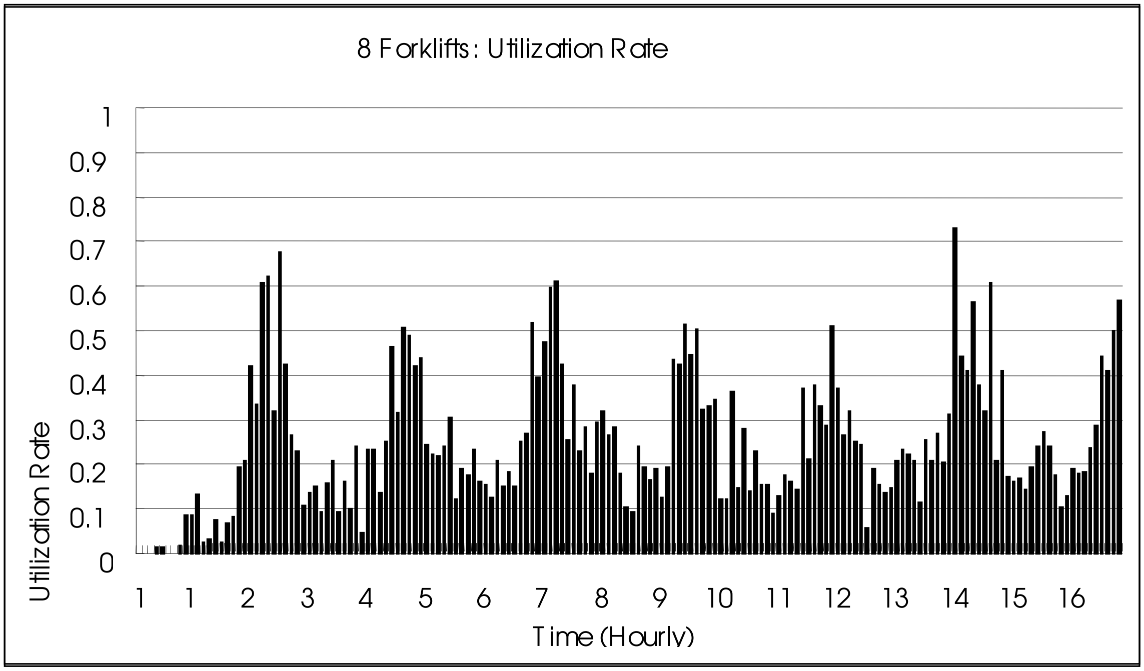


Figure 33: Utilization Rate of Eight Forklifts

As the number of forklifts increases, the maximum value of the utilization rate drops. Besides reflecting the workload sharing among the forklifts, this result also highlights the fact that the increase in the equipment's idle time commensurates with the increase of the number of forklifts. Ideally, based on this information, management people can decide on the number of forklifts to be used in the terminal. However, this judgment could be biased as other crucial factors such as the targeted service level of the terminal should be considered together. Therefore, we have included the study on the responses in terms of average cycle time resulting from the changes in the number of forklifts.

Table 10 shows the effects of the number of forklifts on the terminal's performance. It asserts that if only one forklift is used the average cycle time becomes extremely large. This reinforces our previous assertion that one forklift is definitely unable to cope with the existing demand. When two forklifts are used, the improvement can be discerned. These results indicate that the average cycle time required for the case of two forklifts condition is almost 6.5 times of the average cycle time when the optimal number of forklifts (six) is used. The service level is very far away from the optimal value. It is interesting to note that after the number of forklifts exceeds four, further increase in the number of forklifts only reduces the cycle time marginally. Increasing forklifts beyond six increases the overall cycle time. To maintain a reasonable service level, we can conclude that the current operations require at least three forklifts to be used for general cargo activities. Any number less than that would lead to an unreasonably long cycle time.

Table 10: The Impact of Different Number of Forklifts

Number of forklifts, i	Ratio of overall average cycle time of i forklifts to overall average cycle time of existing number of forklifts	Coefficient of Variation	Ratio of peak average cycle time of i forklifts to overall average cycle time of existing number of forklifts	Coefficient of Variation
1	Infinite	Infinite	Infinite	Infinite
2	6.0859	0.2683	9.8007	0.1592
3	1.2587	0.2501	1.6544	0.2300
4	1.0000	0.0615	1.1624	0.0385
5	0.9584	0.0339	1.0369	0.0591
6	0.9346	0.0366	0.9952	0.0416
7	0.9549	0.0367	0.9854	0.0238
8	0.9624	0.0667	1.0239	0.0592

Note: Overall (Down period and peak period) are considered together during the cycle time calculation.

4.4 The Evaluation of the Clustering Policy

We conducted a study on the proposed clustering policy based upon the existing number of forklifts. The simulation results suggest that the implementation of a clustering policy can lead to significant improvement in service level. This is especially true during the peak period, where we found more than 18% reduction in the time required and the overall improvement including the non-peak periods could attain up to 11.6% reduction in the time required.

4.5 The Evaluation of the Convenience Rule

Besides the clustering policy there has been an attempt to evaluate the impact of the intelligent truck dock allocation policy. However, simulation results show that this intelligent truck dock allocation policy would only improve the service level marginally. We found that this policy reduced the overall average cycle time by 0.6%, and the peak hour average cycle time by 5.1%. This could be due to the fact that the existing terminal is too small and only a few of truck docks are available. Consequently, savings in forklift traveling distances resulting from the application of this policy are unlikely to be significant in this terminal.

4.6 The Evaluation of the Skid-building Rate

A particular difficulty in studying the skid-building rate is there exists a high variance in the observed skid-building rate. To examine this factor, we consider the lower bound of the skid-building rate (2.26 seconds/piece, obtained through a time study) as our reference point for the purpose of comparing later results. From Table 11, the observation seems to suggest that an improvement in the skid-building rate could lead to a significant improvement in the overall performance. For instance, if the skid-building rate has been improved from 7.26 seconds/piece to 2.26 seconds/piece, it could result in an 10.6% (i.e., (0.8436 – 0.7539)/(0.8436)*100%) improvement in the average cycle time. Of more interest from a strategic point of view is that by incorporating a clustering policy at the same time, the service level could be improved further. As shown in Table 12, a skid-building rate of 2.26 seconds/piece, together with the implementation of the clustering policy, can reduce the average cycle time by up to 34.9% (i.e., (1 – 0.6509)*100%), compared with the average cycle time without the clustering policy.

Table 11: The Impact of Skid-building Rate on Average Cycle Time

Skid-building Rate	**(Without Clustering Policy)**			
(seconds/piece)	**Ratio of overall average cycle time with skid-building to overall average cycle time with current rate**	**Coefficient of Variation**	**Ratio of peak hour average cycle time with skid-building rate to overall average cycle time with current rate**	**Coefficient of Variation**
Current rate	**1.0000**	**0.0615**	**1.1624**	**0.0385**
2.26	**0.7539**	**0.0812**	**0.8347**	**0.0690**
7.26	**0.8436**	**0.0433**	**0.9322**	**0.0799**
17.26	**1.0706**	**0.0530**	**1.1784**	**0.0418**
22.26	**1.1992**	**0.0606**	**1.3179**	**0.0756**

Table 12: The Impact of Implementation of Clustering Policy

Skid-building Rate	**(With Clustering Policy)**			
(seconds/piece)	**Ratio of overall average cycle time with clustering policy to current rate's overall average cycle time (without clustering policy)**	**Coefficient of Variation**	**Ratio of peak hour average cycle time with clustering policy to current rate's overall average cycle time (without clustering policy)**	**Coefficient of Variation**
Current rate	**0.8845**	**0.04788**	**0.9480**	**0.0200**
2.26	**0.6509**	**0.04864**	**0.7109**	**0.0159**
7.26	**0.7525**	**0.04293**	**0.7889**	**0.0161**
17.26	**0.9688**	**0.03656**	**1.0376**	**0.0245**
22.26	**1.1128**	**0.05058**	**1.2084**	**0.0276**

CHAPTER 5: CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

A clear conclusion that can be drawn from the simulation results is that the simulation model can help us to identify the peak activity period of an air cargo terminal, to test the adequacy of the amount of equipment to be used, to show the effectiveness of working policies, and the sensitivity of the current terminal's capacity to react to demand changes. There can be little doubt that an insufficient number of forklifts can lead to a very bad service level, particularly during the busy hours. On the other hand, too many forklifts can hurt the overall performance, mainly due to congestion. In short, simulation analysis can be used to identify the optimal number of forklifts.

The price of ignoring the implementation of an appropriate storage policy would be a poor service level, causing a longer waiting time for cargo agents. The simulation study reveals that better terminal performance can be achieved through lesser cargo searching time. Clustering has been recognized as a policy with the potential to provide a pragmatic solution; it displays a significant improvement in the service level, and its implementation is feasible.

Equally important, to improve the current performance of the terminal, we must also aggressively seek to develop close cooperation among the truck dock operation teams. The simulation results of the skid-building rate led us to emphasize the improvement in truck dock activities. The improvement will depend very much on the extent to which cargo agents and truck dock operation ground handlers are able to expedite the cargo skid-building and confirmation jobs.

We saw initially that there is a great potential in an intelligent truck dock allocation policy to improve the current terminal's performance. Obviously, a small terminal has restrictions on the improvements, and only marginal improvement in the service level can be discerned.

Based on the analysis, it is concluded that high mechanization does not guarantee an efficient physical flow system within an air cargo terminal, if one does not pay sufficient heed to rudimentary things such as proper cargo storage policy, efficient truck dock operations and the optimal amount of equipment (e.g., forklifts). The impact of all these fundamental areas become significant especially when the space availability of the terminal is limited and the cargo volume is growing rapidly.

5.2 Recommendations

The healthiest way of treating these problems is to have an initial deep understanding of the current operational conditions. Clearly, incentive schemes could have a key role to play in leveling the workload over time. As the peak period occurs only 25% of the time, incentive schemes could spread the workload to non-peak periods. This would not only help to utilize resources effectively but also could improve service level tremendously.

For instance, for those cargo agents who are willing to retrieve their cargoes during non-peak hours, their cargoes could be allowed to be stored in the terminal for a longer period of time.

Another recommendation flows from the previous conclusion that due to space constraints, there is a limit in terms of the number of forklifts that can be used before the service level starts to deteriorate. Thus, it entails the need to identify the optimal number of forklifts based upon the existing cargo volume level and the terminal's layout.

Our third recommendation concerns manpower issues for truck dock activities. There are two possible ways to expedite the skid-building rate. To have very experienced people in handling truck dock activities is definitely one of the conventional ways to improve the efficiency. However, this stresses the need for the staff training and it takes time. The other way is to gather manpower from both cargo agents and terminal staff. Due to the limited space at truck dock area, too many people at the truck dock might not be appropriate at all. Consequently, a proper manpower planning becomes the key ingredient to ensure the efficiency of the skid-building operation. Surely, this demands for another in-depth study or a relevant analytical model to optimize the number of manpower required in a given truck dock space area and under different level of workload at different period of time.

Another recommendation for improvement of the existing service level is to take advantage of the new technology. For example, Radio Frequency Identification tags

(RFID) can be an useful technology in reducing the cargo searching time in racking systems. RFID tags are small integrated circuits connected to an antenna, which can be attached to cargo, and used to communicate with interrogating RF signals with simple identifying information, or more complex information signals depending on the individual units used.

REFERENCES

Apple, J. M., *Plant layout and material handling*, 3rd Edition, John Wiley & Sons, ISBN 0-471-07171-4, 1977.

Ashford, N. and Fathers, S., An approach to level of service design of air freight terminals for small express parcels, *Transportation Planning and Technology*, **14**, 171-180, 1989.

Ballou, R. H., Improving the physical layout of merchandise in warehouses, *Journal of Marketing*, **31**(3), 60-64, 1967.

Bekey, G. A., *Mathematical models of public systems*, Simulation Councils Proceedings Series, Simulation Councils, Inc., California, **1**, Jan 1971.

Berg, J. P., Class-based storage allocation in a single-command warehouse with space requirement constraints, *International Journal of Industrial Engineering*, **3**(1), 21-28, 1996.

Bovy, P. H. L., *Transportation modeling for tomorrow*, Delft University Press, ISBN 9047-1317-0, 1996.

Chung, Y. G., Randhawa, S. U. and McDowell, E. D., A simulation analysis for a transtainer-based container handling facility, *Computers and Industrial Engineering*, **14**(2), 113-125, 1988.

Dasgupta, A. and Ghosh, M., Inducing performance in queue via prices: the case of a Riverine Port, *Management Science*, **46**(11), 1466-1484, 2000.

Delorme, P., Procter, J., Swaminathan, S. and Tillinghast, T. (1992), Simulation of a combination carrier air cargo hub, *Proceedings of the 1992 Winter Simulation Conferenc*e, 1325-1331.

Farley, J. U. and Ring, L. W., A stochastic model of supermarket traffic flow, *Operations Research*, 555-567, Jul-Aug 1966.

Francis, R. L. and White, J. A., *Facility layout: an analytical approach*, Prentice-Hall Inc., Englewood Cliffs, New Jersey, ISBN 0-13-299149-7, 1974.

Florian, M., *Transportation planning models*, North-Holland, ISBN 0-4448-7581-6, 1984.

Goetschalckx, M. and Ratliff, H. D., Shared storage policies based on the duration of stay of unit loads, *Management Science*, **36**(9), 1120-1132, Sep 1990.

Hansen, J. B., Optimizing ports through computer simulation sensitivity analysis of pertinent parameters, *Operational Research Quarterly*, **23**(4), 519-530, 1972.

Heijden, M. C., Harten, A., Ebben, M. J. R. and Saanen, Y. A., Using simulation to design an automated underground system for transporting freight around Schiphol Airport, *Interfaces*, **32**(4), 1-19, 2002.

Jennings, N. H. and Dickins, J. H., Computer simulation of peak hour operations in a bus terminal, *Management Science*, **5**(1), 106-120, Oct 1958.

Konz, S., *Facility design*, John Wiley & Sons, ISBN 0-471-84224-9, 1985.

Kusiak, A. and Heragu, S. S., The facility layout problem, *European Journal of Operational Research*, **29**, 229-251, 1987.

Lai, K. K., Lam, K. and Chan, W. K., Shipping container logistics and allocation, *Journal of the Operational Research Society*, **46**, 687-697, 1995.

Larson, T. N., March, H. and Kusiak, A., A heuristic approach to warehouse layout with class-based storage, *IIE Transactions*, **29**, 337-348, Apr 1997.

Lee, K. K. T. and Schonfeld, P., Optimal slack time for timed transfers at a transit terminal, *Journal of Advanced Transportation*, **25**(3), 281-308, 1991.

Levary, R. R. and Kalchik, S., Facilities layout-a survey of procedures, *Computers and Industrial Engineering*, **9**, 141-148, 1985.

Luk, M., Hong Kong air cargo terminals to work in synch because of simulation applications, *Industrial Engineering*, **22**(11), 42-45, Nov 1990.

Montreuil, B. and Ratliff, H. D., Utilizing cut trees as design skeletons for facility layout. *IIE Transactions*, **21**, 136-143, 1989.

Napolitano, M., staff at Gross and Associates, *Making the move to cross docking: a practical guide to planning, designing, and implementing a cross dock operation*, Warehousing Education and Research Council (WERC), ISBN 1-892663-18-X, 2003.

Nutt, M. C., *Functional plant planning, layout and material handling*, Exposition Press, New York, LCCCN 0-682-47092-9, 1970.

Oudheusden, D. L. and Boey, P., Design of an automated warehouse for air cargo: the case of the Thai air cargo terminal, *Journal of Business Logistics*, **15**(1), 261-285, 1994.

Rosenwein, M. B., An application of cluster analysis to the problem of locating items within a warehouse, *IIE Transactions*, **26**(1), 101-103, 1994.

Schwind, G. F., A system approach to docks and cross docking, *Material Handling Management, ABI/INFORM Global* , **51**(2), 59-62, Feb 1996.

Seppannen, J. J. and Moore, J. M., Facilities planning with graph theory, *Management of Science*, **17**(4), B242-B253, 1970.

Shabayek, A. A. and Yeung, W. W., A simulation model for the Kwai Chung container terminals in Hong Kong, *European Journal of Operational Research*, **140**, 1-11, 2002.

Shami, M., A cost-schedule decision support system, *Transactions of AACE International*, CS21.1-21.7, 1996.

Shayam, E., and Ghotb, F., Investigation of port capacity under a new approach by computer simulation, *Computers and Industrial Engineering*, **42**, 533-540, 2002.

Smulders, S. A., *Control of freeway traffic flow*, CWI Tracts, Netherlands, ISBN 9061-9645-12, 1996.

Snowdon, J. L., MacNair, E., Montevecchi, M., Callery, C. A., El-Taji, S. and Miller, S., IBM journey management library: an arena system for airport simulations, *Journal of the Operational Research Society*, **51**, 449-456, 2000.

Tahar, R. M. and Hussain, K., Simulation and analysis for the Kelang container terminal operations, *Logistics Information Management*, **13**(1), 14, 2000.

Tompkins, J. A. and White, J. A., *Facilities planning*, John Wiley & Sons, ISBN 0-471-03299-9, 1984.

Transportation Research Board, National Research Council, Washington, D. C., *Highway capacity manual*, Special Report 209, 3rd Edition, ISBN 0-309-05516-4, 1994.

Tugcu, S., A simulation study on the determination of the best investment plan for Istanbul seaport, *Journal of the Operational Research Society*, **34**(6), 479-487, 1983.

Yun, W. Y. and Choi, Y. S., A simulation model for container-terminal operation analysis using an object-oriented approach, *International Journal of Production Economics*, **59**, 221-230, 1999.

APPENDIX

Cargo Attributes

We have devised a twelve-step procedure for generating air cargo data in a realistic manner:

1. Input Flight Schedule

Input flight schedule data, consisting of flight arrival times, aircraft types, and flight numbers.

2. Generate number of ULDs

Generate the total number of ULDs based on aircraft type.

3. Poisson Regression Model

Build and use a nonlinear Poisson Regression Model to generate the predicted mean number of distinct AWBs. In this project, StatGraphics software is used to find the Poisson Regression equation of best fit to describe the relationship between the predicted average number of AWBs and the number of ULDs. The equation of the fitted *Poisson Regression Model* is in the following form:

$$NumAWB = A * NumULD^{b}$$

where $NumAWB$ = predicted average number of AWBs

$NumULD$ = number of ULDs

A, b = constants

4. Poisson Distribution for generation of Number of Distinct AWBs

Input the predicted mean number of AWBs generated previously into a Poisson distribution to generate the actual number of distinct AWBs.

5. Empirical Distribution for AWB number Assignment to ULD

Construct an empirical distribution from actual data and use it to generate the total number of ULDs in which each AWB number's cargo is to be stored. For each distinct AWB number, it is possible for different cargo with the same AWB number to be stored in several ULDs. To incorporate this aspect, data analysis of the actual data was performed (as summarized in Figure 1). Almost 20% of the AWBs have cargo stored in more than one ULD. Since the number of cases where the same AWB number exists in more than six ULDs is extremely low, it is not considered in our study. At this stage, it is necessary to ensure that

$$\text{NumULD} > N_2 + 2N_3 + 3N_4 + 4N_5$$

where N_i = total number of distinct AWBs that have cargo in i ULDs;

6. Assignment of AWB numbers to ULDs

A simple algorithm is used to assign AWB numbers to ULDs:

6.1 Algorithm 1.0

N_i = Total number of distinct AWB numbers with cargo in exactly i different ULDs.

i. First, allocate one ULD to each distinct AWB number that has with cargo allocated to more than one ULD.

ii. Then, the balance of the number of ULDs is calculated as follows:

BalanceNumULD = NumULD – (N_2 + $2N_3$ + $3N_4$ + $4N_5$)

iii. The next step is to assign the first total number of distinct AWB numbers to the balance of the ULDs (= BalanceNumULD).

iv. Lastly, randomly assign the rest of the total number of AWB numbers (= NumAWB – BalanceNumULD) to the balance of the ULDs (=BalanceNumULD).

7. Generate ULD's weight

Build a probabilistic distribution to generate ULD's weight. The Arena analyzer was used to find the best-fitting probability distribution.

8. Assignment of cargo weight value to each AWB number

Another simple algorithm is used to assign cargo weight value to each AWB number:

Algorithm 2.0

i. For a given ULD with total weight = $\boldsymbol{w}$, with $\boldsymbol{n}$ distinct AWB numbers, $\boldsymbol{n}$ random numbers from **U~U(0,1)** are generated to get the value of $\boldsymbol{p_1, p_2, ..., p_{n-1}, p_n}$.

ii. Calculate $\boldsymbol{P}_1 = \frac{\boldsymbol{p}_1}{\sum_i \boldsymbol{p}_i}$, $\boldsymbol{P}_2 = \frac{\boldsymbol{p}_2}{\sum_i \boldsymbol{p}_i}$, $\boldsymbol{P}_3 = \frac{\boldsymbol{p}_3}{\sum_i \boldsymbol{p}_i}, \ldots,$ $\boldsymbol{P}_n = \frac{\boldsymbol{p}_n}{\sum_i \boldsymbol{p}_i}$.

iii. The i[th] AWB is then assigned with cargo weight value = $\boldsymbol{P_i}*\boldsymbol{w}$, for i = 1, …, n. In other words:

cargo weight of 1[st] AWB = $\boldsymbol{P_1}*\boldsymbol{w}$

cargo weight of 2[nd] AWB = $\boldsymbol{P_2}*\boldsymbol{w}$

…

Note: The idea of this algorithm is similar to the Dirichlet distribution.

9. <u>Generate Pieces of Cargo Information</u>

In generation of pieces of cargo data, another type of probabilistic distribution is applied. In our project, we use three separate cargo-pieces distributions to capture this feature. Again, the Arena analyzer is used to search for the best fitting distributions.

10. <u>Cargo Agent Type</u>

An empirical distribution is used to divide the cargo agent into two categories: big cargo agent or small cargo agent.

11. <u>Cargo Agent Request Time</u>

Two separate request time empirical distributions are formed to generate two types of request time data to model request time behavior of big cargo agents and small cargo agents.

12. Cargo Storage Location

To assign storage location attributes to each load, we calculated the probability value for each storage system's cargo in different cargo weight categories. The results are summarized in Table 2.